Template revision date – 09-10-13

WQIR-IP TEMPLATE

Directions to authors:

This template is for submittal of a **TMDL with implementation plan**.

Read and delete text in **{**brown**}**, and fill in text highlighted in yellow.

WQP author and EAP author work *jointly* on this document.

Use WQI SHAREPOINT – DOCUMENT REVIEW
Contact WQI SharePoint Coordinator (WQP) to set up project work area

WQP staff is responsible for overall document, working jointly with EAP staff as appropriate.

EAP staff writes Technical Study (plain-talked by EAP Publications staff), with WQP staff input as appropriate.

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- Keep the caption style for **figure and table titles** as set in this template: **Arial 10**. Figure/table number and title is **bolded**. Keep table and figure titles **short and succinct**. Format any **other caption text in *italics*, unbolded**.
- Center figures and tables.
- **Line up** the left margin of figure and table titles **with the left margin** of the figure or table. Do not use a hanging indent.
- Use **Arial 9 or 10** or other non-serif font **in tables** (unless must use smaller font such as 8 or 9).
- **Left-justify** all bullets.
- Do not change "%" in the text of the technical sections to "percent."
- Spell "water body" as two words, unless it's used as an adjective, then hyphenate: "water-body".
- Keep **two spaces between sentences** as done in the technical sections.
- Put **two spaces after colons and periods** used at the end of sentences.
- Do not use a "Draft" watermark. "Draft" is already on the front page and in the footer of this template.
- **Executive Summary**: Formatting is specific to the ES. It is meant to be a stand-alone document.

Please do not change the formatting or fonts in the standard language.

If you see something you think needs correcting please contact the WQI Publication Coordinator (WQP).

The following checklist and router is for WQ staff use only. EAP staff have a different checklist.

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WQIR-IP REGIONAL PRODUCTION CHECKLIST and ROUTER

Date: ________ **Author:**____________________ **Publication No:**______________**WRIA:** ____

SIC (for printing): ________________________

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All HQ reviews go through Melissa Gildersleeve. Final publications go to HQ-WQ for publishing.
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STEP	PROCESS	INITIAL	DATE
To START	**WQIR LEAD** requests **WQI SHAREPOINT ADMINISTRATOR** (Dustin Bilhimer) to establish a project folder in the **WQI Reports in Production** section.		
1.	**USING WQIR-IP TEMPLATE** (in the WQI project folder, **WQIR LEAD** coordinates with EAP to develop document.		
2.	**If developing WLAs/BMPs for municipal, construction, or industrial stormwater**, begin consulting with appropriate stormwater permit manager.		
3.	When ready for reviews, **WQIR LEAD** places draft document in the WQI Doc Center Library/WQI Reports in Production project folder in the WQI SharePoint. (*Note*: once the document is in the SharePoint folder it is the *official* version. **All other drafts should be deleted.**)		
4.*	**WQIR LEAD** has EA or WQ Program perform technical review following the review policy. When technical review is complete, save completed form in WQI SharePoint project folder with WQIR-IP document.		
5.*	**WQIR LEAD** has HQ Watershed Management Section perform policy review following the review policy. When policy review is complete, save completed form in WQI SharePoint project folder with WQIR-IP document.		
6.*	**WQIR LEAD** and **WQI PUBLICATIONS COORDINATOR** (Diane Dent) work together to finalize the count of 303(d) listings addressed in the WQIR-IP.		
7.	**WQIR LEAD** has document go through internal review for **Plain Talk** and peer review by other WQIR leads (this step may take time as various staff comment back and forth).		
8.	**UNIT SUPERVISOR** reviews, comments and returns document to author.		
9.	**WQIR LEAD** with EAP counterpart (as applicable) incorporates comments/changes, notifies regional secretary that document is ready for review.		
10.	**REGIONAL SECRETARY** reviews document (grammar, punctuation, spelling), notifies WQIR Lead when complete.		
11.	**SECTION MANAGER** reviews, comments, sends back to WQIR Lead.		
12.	**WQIR LEAD** incorporates comments (as applicable), notifies **HQ WQI PUBLICATIONS COORDINATOR** (Diane Dent) by email that document is ready for publication. **GO TO PUBLICATION ROUTER.**		
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* #s 4, 5, 6 may be done in any order, at the discretion of the TMDL project lead

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Pilchuck River Temperature and Dissolved Oxygen Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan - DRAFT

DEPARTMENT OF ECOLOGY
State of Washington

[Month Year]
Publication no.[xx-10-xxx]

Publication and Contact Information

This report is available on the Department of Ecology's web site at https://fortress.wa.gov/ecy/publications/SummaryPages/1x10xxx.html

For more information contact:

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- Central Regional Office, Yakima 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

Cover photo: Pilchuck River impaired riparian zone and streambank.

Project Codes and 1996 303(d) Water-body ID Numbers

Commented [DTD1]: This date and WBID numbers need to be in your document until a new agreement with EPA has been signed

Data for this project are available at Ecology's Environmental Information Management (EIM) website at www.ecy.wa.gov/eim/index.htm. Search Study ID TSWA0004.

Activity Tracker Code (Environmental Assessment Program) is 12-067.

TMDL Study Code (Water Quality Program) is xxxxxx.
{To find the code, go to the TMDL Management Database at http://ecywblcyadnet01/tmdl/ and select "TMDL Reports" and then "Study/Submittal Status." Use the arrows at the top of the screen (starting from the first or last record) to find your study. If the study isn't there, contact the TMDL project lead.}

Water Resource Inventory Area (WRIA) for this study: 07.

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Pilchuck River
Temperature and Dissolved Oxygen
Total Maximum Daily Load

Water Quality Improvement Report
and
Implementation Plan

by

Nuri Mathieu
Environmental Assessment Program

and

Heather Khan
Water Quality Program
Northwest Regional Office

and

Ralph Svrjcek
Water Quality Program
Northwest Regional Office

Washington State Department of Ecology
Olympia, Washington

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Table of Contents

List of Figures

List of Tables

{To update, click on either side of the above lists, then press F9 on your keyboard.}

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- References
- Insert Caption
  Choose “Figure” or “Table”

Don’t add captions to figures and tables in the Appendices.

Don’t cross-reference your figures and tables in the text. These cross-references often become corrupted when using the file, printing, or converting to pdf – causing many problems.

Acknowledgements

The authors of this report thank the following people for their contribution to this report and plan:

- French Slough Flood Control District
- SWM/SCD/nonprofits/tribal staff
- Laurie Mann of EPA
- Advisory Group members
- xx
- xx
- xx
- Washington State Department of Ecology staff
    - xx
    - xx
    - xx

Abstract

Previously collected water quality data indicates that the Pilchuck River has high water temperatures and low dissolved oxygen (DO) levels that do not protect fish and native insects that depend on cool, clean, aerated water. This report documents these problems and outlines the solutions needed to improve stream temperatures and DO levels.

From 2012 to 2016, Ecology collected data on the Pilchuck River in order to develop a water quality model. The model was then used to evaluate future management options and develop allocations for shade and phosphorus. The study area for this Total Maximum Daily Load (TMDL) includes the mainstem of the Pilchuck River from Menzel Lake Rd upstream of Granite Falls, Washington to near its mouth with the Snohomish River, as well as the watershed area contributing to this reach.

The primary cause of temperature problems in the Pilchuck River is lack of shade from streamside trees. This report establishes the necessary amount of shade (load allocations) for the Pilchuck River study area. The shade produced by full potential riparian vegetation (mature 50-100 year old trees) is needed to meet water quality standards in the Pilchuck River. It also specifies the allowable amount of heat load contributed from permitted entities in the watershed (wasteload allocations).

The primary cause of DO problems in the Pilchuck River is excess phosphorus contributing to increased growth of algae on the stream bottom. These algae consume oxygen at night, leading to lower DO levels.

pH was not predicted to exceed Washington State Water Quality Standards under critical conditions within the study area. Loss of riparian shade and increased nutrient loading impacts on DO are more severe than on pH, therefore the allocations for shade and nutrients should result in compliance with pH standards during the summer critical season.

This report includes the allowable amount of phosphorus loading to the river for several permitted entities (wasteload allocations) and from groundwater, direct overland flow, or tributary streams (load allocations) in the watershed. It also outlines activities that will reduce phosphorus delivery from various discharges and land uses within the watershed.

Executive Summary

{EAP and WQP TMDL project leads write this section.

Needs to be ≤ 4 pages – and able to "stand alone."

The audience for this section includes: permit writers, stakeholders, and the general public, among others.

Keep this format. Do not change this section to a two-column format.

This is a highly condensed version of the report.}

xx

Introduction

{Start with a paragraph briefly summarizing the watershed, issue, and TMDL process. E.g.: "In 2004, Ecology determined that ABC Creek has <pollutant> levels greater than Washington State allows in its fresh waters. A total maximum daily load, or TMDL study, was done on this water body. This water quality improvement report contains the study, along with recommendations for cleaning up the water body, and an implementation plan that lays out roles and responsibilities for the cleanup process."}

xx

Why did we develop a total maximum daily load (TMDL)?

The federal Clean Water Act (CWA) requires that a TMDL be developed for each of the water bodies on the 303(d) list. The 303(d) list is a list of water bodies, which the CWA requires states to prepare, that do not meet state water quality standards. The TMDL study identifies pollution problems in the watershed, and then specifies how much pollution needs to be reduced or eliminated to achieve clean water. Then Ecology, with the assistance of local governments, agencies, and the community develops a plan that describes actions to control the pollution and a monitoring plan to assess the effectiveness of the water quality improvement activities. The water quality improvement report (WQIR) consists of the TMDL study findings and implementation plan.

Watershed description

This study area is in Water Resource Inventory Area (WRIA) 07, the Snohomish River basin.

- {Goals and objectives: clean water, uses

- Watershed description, including a map of the area subject to the TMDL allocations summary.}

xx

What needs to be done in this watershed?

{Briefly summarize recommendations to bring the water body back to compliance with water quality standards. Include a brief summary of load and wasteload allocations, as appropriate. Load allocations may be displayed in a table that describes parts of the watershed where they apply and should also be displayed on a map.
Table 1 can be modified as necessary to include all of the dischargers in the TMDL study, unused columns can be deleted, or the entire table can be excluded if there are no point sources in the TMDL.}

xx

Table 1: Wasteload allocations for NPDES permitted dischargers *(example—may not have wasteload allocations for separate components of stormwater.)*

Water-body Name	Parameter of Concern	Time Period Restrictions	Permittee Name and ID	Permit Type	Wasteload Allocation
No Name Creek	Turbidity	June-August	River Valley Housing Development.	Construction Stormwater	
		Jan-Dec	Dig It Up Mine	Sand & Gravel	
American River	FC	July-August	Pleasantville STP	WWTP discharge	
	FC	Sept-Nov	Town of Pleasantville	Municipal Stormwater	
	BOD	Jan-Dec	Corn Processing Plant	Industrial discharge	
	Phosphorus		Future development inside the Pleasantville UGB	Construction Stormwater[1]	

{Table should refer to map to be specific about where wasteload allocations apply—not just to segments.

- Conclusions and recommendations
- Include summary for seasonal variation and future sources (growth)
- Implementation Summary (WQP staff writes this part)}

xx

Why this matters

{Briefly describe the importance of this project. Consult your PIO for messaging ideas. Alternatively, you can incorporate the "why this matters" messaging in other appropriate sections of the Executive Summary, as well as the main body of the report.
WQP Intranet has some examples that you can copy and paste into this document as part of the message.}

Reducing high water temperatures and improving dissolved oxygen (DO) levels in the Pilchuck River watershed is necessary to recover threatened cold water fish species that spawn, rear, or live there. These fish species are highly valued by the many state residents that depend upon them for cultural, recreational, or economic reasons. Over the past century, the lands of this watershed have seen many changes as they were developed to provide lumber, agricultural land, homesteads, water supplies, and locations to dispose of treated domestic wastewater and stormwater. This watersheds has several urban centers that are expected to grow in size and impact the watershed. Agricultural activities are expected to thrive and recreational use can be expected to grow. Many of these activities could affect stream temperatures and DO levels in the future.

This report studies this changed environment, reports on the state of water temperatures and DO levels now, what we can expect in the future, and what we need to do to improve degraded areas of these watersheds.

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Commented [nlm3]: To be completed jointly by WQP and EAP in the future Do not review this section

What is a Total Maximum Daily Load (TMDL)

A TMDL is a numerical value representing the highest pollutant load a surface water body can receive and still meet water quality standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

Federal Clean Water Act requirements

The Clean Water Act (CWA) established a process to identify and clean up polluted waters. The CWA requires each state to have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of (1) designated uses for protection, such as cold water biota and drinking water supply, and (2) criteria, usually numeric criteria, to achieve those uses.

Commented [NE(4]: I'm used to seeing "aquatic life" in the WQ standards, but this is good also

Commented [nlm5R4]: Noted; this is boilerplate from WQP, so I will defer to their preference

The Water Quality Assessment and the 303(d) List

Every two years, states are required to prepare a list of water bodies that do not meet water quality standards. This list is called the CWA 303(d) list. In Washington State, this list is part of the Water Quality Assessment (WQA) process.

To develop the WQA, the Washington State Department of Ecology (Ecology) compiles its own water quality data along with data from local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data in this WQA are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the assessment. The WQA divides water bodies into five categories. Those not meeting standards are given a Category 5 designation, which collectively becomes the 303(d) list.

Commented [NE(6]: Doesn't Category 4 also include water bodies not meeting standards?

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Category 1 – Meets standards for parameter(s) for which it has been tested.

Category 2 – Waters of concern.

Category 3 – Waters with no data or insufficient data available.

Category 4 – Polluted waters that do not require a TMDL because they:

- 4a. – Have an approved TMDL project being implemented.
- 4b. – Have a pollution control program in place that should solve the problem.
- 4c. – Are impaired by a non-pollutant such as low water flow, dams, or culverts.

Category 5 – Polluted waters that require a TMDL – the 303(d) list.

Further information is available at Ecology's Water Quality Assessment website (www.ecy.wa.gov/programs/wq/303d).

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The CWA requires that a TMDL be developed for each of the water bodies on the 303(d) list.

TMDL process overview

Ecology uses the 303(d) list to prioritize and initiate TMDL studies across the state. The TMDL study identifies pollution problems in the watershed and specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology, with the assistance of local governments, tribes, agencies, and the community, develops a plan to control and reduce pollution sources as well as a monitoring plan to assess effectiveness of the water quality improvement activities. This comprises the *water quality improvement report* (WQIR) *and implementation plan* (IP). The IP section identifies specific tasks, responsible parties, and timelines for reducing or eliminating pollution sources and achieving clean water.

After the public comment period Ecology addresses the comments as appropriate. Then, Ecology submits the WQIR/IP to the U.S. Environmental Protection Agency (EPA) for approval.

Who should participate in this TMDL process?

Because thermal and nutrient pollution comes from diffuse sources, all upstream watershed areas have the potential to affect downstream water quality. Therefore, all areas contributing excessive levels of solar radiation, or other factors contributing to high water temperature, must use the appropriate best management practices to reduce impacts to water quality. The area subject to the TMDL is shown in Figure 1.

Streamside landowners are the most important participants in reducing water temperatures in the Pilchuck River watershed and meeting the nonpoint pollutant load targets. Governmental and private organizations that provide technical assistance and other support to these landowners are critical partners that need to work with these landowners to improve riparian shading of local waters. Regulatory agencies responsible for managing forestry practices and public lands are also essential participants. Specific agencies, organizations, and their role in reducing water temperatures are discussed in more detail in the *implementation plan* at the end of this document.

The Granite Falls wastewater treatment plant (WWTP) and municipal separate storm sewer system (MS4) discharges from Snohomish County, the cities of Snohomish, Granite Falls, Marysville, and WSDOT received limitations on their nutrient and thermal discharges. Ecology will ensure compliance with these limitations through the provisions of their National Pollutant Discharge Elimination System (NPDES) permits. These permits will be discussed in more detail below and in the *implementation plan* at the end of this document.

Commented [NE(9]: I found this section confusing to read, it seems to get into implementation activities but maybe that's necessary Consider more of a bullet list format if that seems appropriate to you:

Who should participate?
--Streamside landowners
--Gov't and private organizations
--Regulatory agencies
--Point source dischargers
--Nonpoint source landowners

Giving a brief description of each entity somehow

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Why repeat it?

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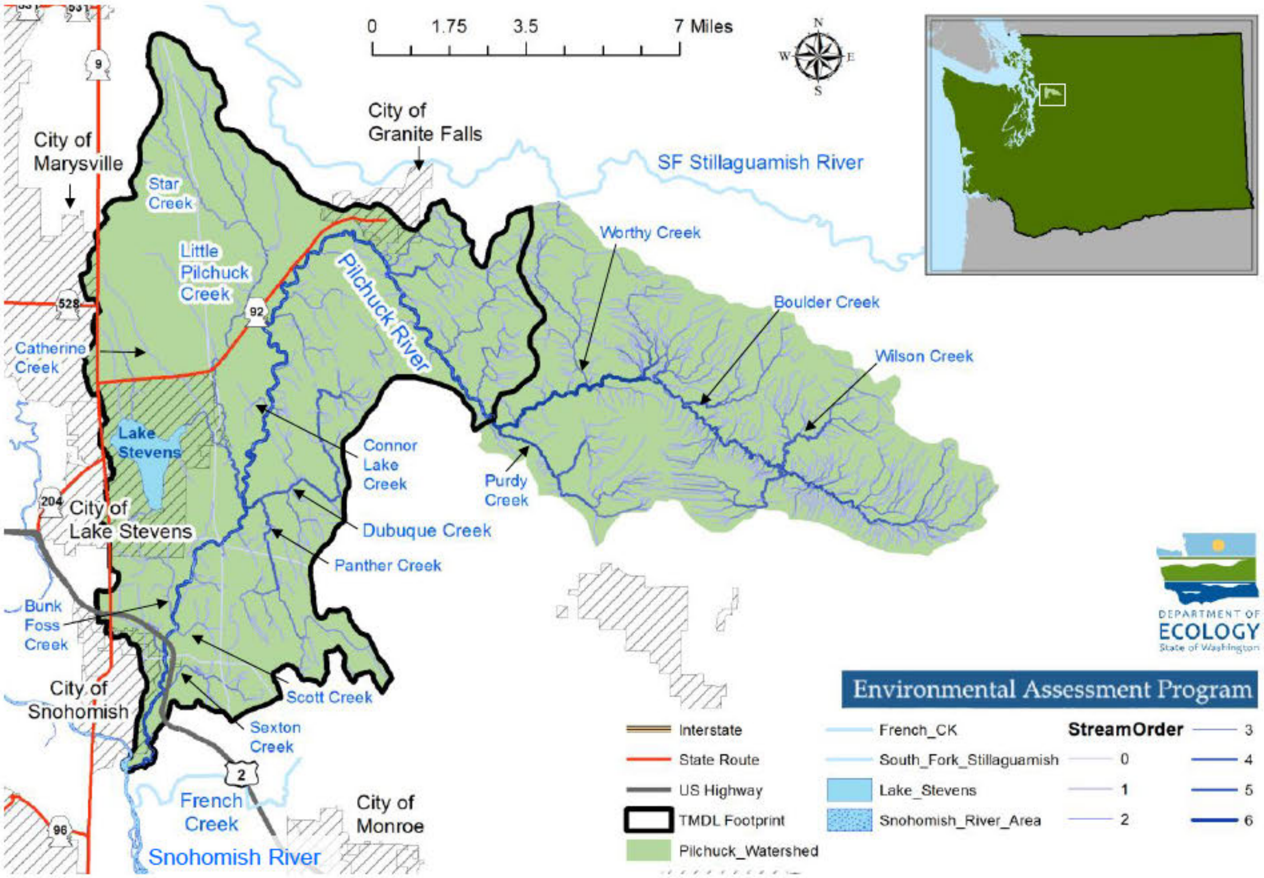

Figure 1. Pilchuck River watershed and TMDL study area.

Elements the Clean Water Act requires in a TMDL

Loading capacity, allocations, seasonal variation, margin of safety, and reserve capacity

A water body's *loading capacity* is the amount of a given pollutant that a water body can receive and still meet water quality standards. The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a water body into compliance with the standards.

The portion of the receiving water's loading capacity assigned to a particular source is a *wasteload* or *load* allocation. If the pollutant comes from a discrete (point) source subject to an NPDES permit, such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation* (WLA). If the pollutant comes from diffuse (nonpoint) sources not subject to an NPDES permit, such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation* (LA).

The TMDL must also consider *seasonal variations* and include a *margin of safety* (MOS) that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A *reserve capacity* (RC) for future pollutant sources is sometimes included as well.

Therefore, a TMDL is the sum of the wasteload and load allocations, any margin of safety, and any reserve capacity. The TMDL must be equal to or less than the loading capacity.

$$WLA + LA_1 + LA_2 + MOS + RC = \text{MAXIMUM DAILY LOAD}$$

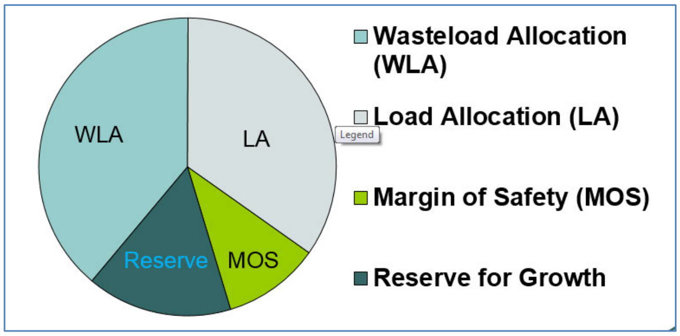

Figure 2. Pie chart showing components of a TMDL

Why Ecology Conducted a TMDL Study in this Watershed

{This section is written by WQP lead.}

Background

Improving water quality in the Pilchuck River watershed is necessary to support the recovery of threatened cold water fish species that spawn, rear, or live there. Chinook, Coho, Sockeye, Chum, and Pink Salmon as well as bull trout and steelhead trout call the Pilchuck River home. These fish species are highly valued by the many state residents that depend upon them for cultural, recreational, or economic reasons. The Pilchuck River contains mainstem primary and secondary restoration areas targeted for restoration of endangered Chinook salmon (Snohomish Basin Salmon Recovery Forum, 2005).

The Pilchuck River watershed drains into the upper end of the tidal portion of the Snohomish River. Studies collected data on high water temperatures and low DO levels in the Pilchuck River watershed in the early 1990s (Tooley et al., 1990; Thornburgh et al., 1991) and the data set expanded over the next decade (Thornburgh and Williams, 2000).

The high water temperatures and low dissolved oxygen (DO) levels found in these studies do not protect fish and other native species that depend on cool, clean water (Figure 1). As a result, these water segments were included on the 303(d) list. In recent years much more data have become available indicating more widespread impairment. In response to these listings and the more recent data, Ecology is preparing a Water Quality Improvement and Implementation Plan.

The Pilchuck River and its tributaries are also impaired by high bacteria levels. This report does not address bacteria pollution, because Ecology previously addressed bacteria pollution problems in the Snohomish River Tributaries Fecal Coliform (FC) Bacteria TMDL (Wright et al., 2001) and its implementation plan (Svrjcek, 2003).

During the 2004 and 2009 WRIA 7 water quality scoping processes, Ecology consulted with watershed stakeholders and determined that implementing the existing bacteria TMDL should continue in the Pilchuck River watershed to reduce both bacteria and nutrient loading problems that can lead to low DO levels. Those implementation efforts would focus on riparian plantings as well to more directly support salmon recovery efforts. However, in late 2011, EPA made new TMDL funding available and Ecology chose to start the Pilchuck River and Skykomish River TMDLs ahead of schedule to local compliment salmon recovery efforts.

Commented [PP(24]: citations?

Commented [nlm25R24]: Noted will ask Ralph

Local organizations applied for and received Ecology funds for several water cleanup projects. The Snohomish Conservation District worked with the city of Snohomish on education/outreach and a low-impact development project. The Adopt-A-Stream Foundation carried out door-to-door outreach and riparian plantings in the Little Pilchuck Creek basin. Ecology helped facilitate a streamside restoration project in Dubuque Creek. More recently, Ecology has also funded additional Adopt-A-Stream Foundation projects in the Little Pilchuck to restore riparian areas, most notably their several partnerships with the city of Lake Stevens.

Figure 3. Deceased fish found in isolated low oxygen habitat in the Pilchuck River.

This TMDL:

- Characterizes water temperatures, DO, pH, and the processes that affect those parameters
- Sets the limitations needed on controllable point sources of pollution.
- Details the riparian and riverine improvements needed to make the Pilchuck River a healthy place for fish and supporting biota.
- Provides a detailed plan to help guide Ecology and other stakeholders in our work to:
    - Restore and protect aquatic life uses set forth in Washington Administrative Code (WAC) 173-201A.
    - Implement the Puget Sound Action Agenda, the WRIA 7 Chinook Salmon Recovery Plan, and the anticipated Threatened Steelhead Trout Recovery Plan currently under development.

Impairments addressed by this TMDL

The beneficial uses of the Pilchuck River and its tributaries include:

- *Aquatic Life Use* for salmonid (from mouth to Boulder Creek) and char (upstream of Boulder Creek) habitat, spawning, rearing, and migration.
- *Extraordinary Primary Contact Recreation*
- *Water Supply Uses* for domestic consumption, industrial production, and agriculture or hobby farm livestock
- *Miscellaneous Uses* for wildlife habitat, harvesting, commerce/navigation, boating, and aesthetics (WAC 173-201A-600).

Washington State established Water Quality Standards (Chapter 173-201A WAC) to protect these beneficial uses. Table 2 lists the water bodies within the study area that exceed DO and temperature criteria established in those standards. These impairments are addressed in this TMDL.

Table 2. 303(d) and category 2 listings addressed by this TMDL study.

Waterbody	Listing ID	Parameter Name	NHD Reach Code/ Assessment Unit ID	2014 Category
Pilchuck River	10621	Dissolved Oxygen	17110011000048	5
	7295	Temperature	17110011000061	5
	10620	Temperature	17110011000048	5
	14725	Temperature	17110011000064	5
	72567	Temperature	17110011000065	5
	73874	Temperature	17110011000060	2
Category 2 – Waters of concern.				
Category 5 – Polluted waters that require a TMDL.				

As a result of the data collected in 2012 and 2016 by Ecology for this TMDL study, additional water-body segments were found that do not meet state water quality standards (see Table 3). These segments are also addressed by this TMDL.

Commented [PP(26]: ? not the use supported by temperature and DO criteria

Commented [nlm27R26]: Noted WQP will decide

Commented [SR(28]: I believe we determined that there is an error in the WQ Standards regarding recreational contact standards Need to review this with Patrick on how to address this Might need to footnote the problem in the WQ Standards and address in the next WQ Standards revision

Commented [nlm29R28]: Could we just do as Paul suggests and delete from this list since temp and DO don't influence this use?

Commented [PP(30]: ditto

Commented [nlm31R30]: Noted WQP will decide

Commented [SR(32]: Heather can you see if this list needs updating? May have changed as per the 2012/14 WQ Assessment Not sure about keeping the Cat 2 listings right now

Commented [KH(33R32]: 303 (d) listings confirmed for Table 2 and Table 4 from WQ atlas No updates needed

Commented [nlm34R32]: That's because I updated for the current assessment ☺ Not clear if you want Cat 2 or not, so I left for now

Commented [PP(35]: Third party data? Or recon data? Or part of the study results?

Table 3. Additional impaired waterbody segments addressed by this TMDL (not currently on 303(d) list).

Parameter	NHD Reach Code/ Assessment Unit ID	Basis
Dissolved Oxygen	17110011000049	2016: 3 of 3 daily min excursions at PIL3.6
	17110011000052	2016: 3 of 3 daily min excursions at PIL5.7 2012: 6 of 6 daily min excursions at PIL5.7
	17110011000053	2012: 6 of 6 daily min excursions at PIL8.5
	17110011000061	2012: 3 of 3 daily min excursions at PIL10.4
	17110011000062	2016: 3 of 3 daily min excursions at PIL11.6
	17110011000063	2016: 3 of 3 daily min excursions at PIL15.1 and PIL18.7
	17110011000064	2016: 3 of 3 daily min excursions at PIL21.5
Temperature	17110011000052	2012: 7-DADMax excursions at PIL5.7
	17110011000053	2016: 3 of 3 daily max excursions at PIL8.2
	17110011000062	2016: 3 of 3 daily max excursions at PIL11.6
	17110011000063	2012: 7-DADMax excursions at PIL15.1
Note: Station locations (PIL-XX) refer to river mile from the mouth of the Pilchuck.		

Commented [PP(36]: cite? Or are these results from this study?

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Some 303(d) listed segments in the watershed were not specifically modeled as part of this report but are addressed by this TMDL (Table 4) The details are discussed in the TMDL analysis section of this report.

Commented [SR(38]: Nuri If you would really like to keep Table 4 then I think we need to reword this sentence I am taking a guess why you proposed Table 4 as is but perhaps these occurred outside the critical period?

Commented [nlm39R38]: I think we're required/expected to include anything we don't address

Table 4. 303(d) or Category 2 segments not addressed by this report

Waterbody	Listing ID	Parameter	NHD Reach Code/ Assessment Unit ID	2014 Category
Pilchuck River	7291	pH	17110011000048	5
Little Pilchuck Creek	9274	Dissolved Oxygen	17110011000188	5
	9275	Temperature	17110011000188	5
	40817	pH	17110011000188	5
	40911	Dissolved Oxygen	17110011000072	5
	40912	Temperature	17110011000072	2
Dubuque Creek	7400	Dissolved Oxygen	17110011000054	5
	7401	Temperature	17110011000054	5
	40816	pH	17110011000054	2
Catherine Creek	7394	Dissolved Oxygen	17110011000073	5
	7395	Temperature	17110011000073	5
	40930	pH	17110011000073	5
Unnamed Creek (Tr b To Pilchuck River)	47441	Dissolved Oxygen	17110011000180	5
	71217	pH	17110011000217	5
	73910	Temperature	17110011000217	2

Commented [SR(40]: If the pH listings are outside our study period I am guessing we cannot include them here

Commented [nlm41R40]: Yes, let's discuss how much we want to address this in the TMDL I've included the paragraph on wet season pH below

Commented [MC(42]: Changed the line color within groups Makes it easier to distinquish

For pH, all the excursions are low pH measured during the wet season. Low pH can be the result of natural wetland flushing or acidic rainfall events in naturally poorly buffered systems

(Mathieu, 2011). These excursions may not be related to anthropogenic impact and are likely not tied to the same sources of impairment causing low-flow DO and temperature problems.

Water Quality Standards and Numeric Targets

The Washington State Water Quality Standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, waterbody classifications, and numeric and narrative water quality criteria for surface waters of the state. This section provides Washington State water quality information and those standards applicable to the Pilchuck River watershed. Additional detailed information on the applicable water quality standards is available in Appendix G.

Commented [PP(43]: To me, it seems out of order to list impairments and then list the standards that produces the impairments
Better, I think, to explain the standards, and then list the waterbodies that fail to meet the standards

Commented [nlm44R43]: WQP's call, their template

Commented [SR(45]: I think we are supposed to capitalize Water Quality Standards Alone standards is OK, but when referring to the actual regulation we probably should be more formal Let's do a search and replace later after we verify this

Commented [nlm46R45]: Fine by me This is WQP boilerplate, so should probably update the template if that is the case

Segments of the Pilchuck River and its tributaries are identified on the Washington State 2014 303(d) list as being impaired by excess temperature. Temperature affects the physiology and behavior of fish and other aquatic life. It also affects the physical and biological properties of the water body which can increase the harmful effects of other pollutants and stream characteristics. For example, the warmer a stream is, the less oxygen it can hold for the organisms the stream supports. Therefore, temperature is an influential factor which can limit the distribution and health of aquatic life.

Temperatures in streams fluctuate over the day and year in response to changes in solar energy inputs, meteorological conditions, river flows, groundwater input, and other factors. Human activities can influence each of these factors to impair the health of the water by increasing the temperature, or by improving these conditions to promote cooler temperatures.

Washington's numeric water quality criteria are based on the temperature needs of the most sensitive species supported by the water body. These cool temperature requirements are expressed as the highest allowable 7-day average of the daily maximum temperatures (7-DADMax) in a water body – or in some specified water bodies, the allowable daily maximum temperature.

The change from a daily maximum to a 7-DADMax metric for the majority of the state's streams was determined by scientists involved in the development of EPA's Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (2003[1]) to include an adequate magnitude and duration (averaging period) to protect salmonids. The 7-DADMax temperatures represent conditions in the thalweg or main stream channel; therefore it is assumed that aquatic species have access to cold water refugia where they can reside in water that is cooler than the 7-DADMax temperatures. The 7-DADMax temperature criterion also assumes that colder temperatures are available to protect fish at night.

In the state water quality standards, aquatic life use categories are described using key species (salmon versus warm-water species) and life-stage conditions (spawning versus rearing) [WAC 173-201A-200; 2003 edition].

In this TMDL, the designated aquatic life uses to be protected are *core summer salmonid habitat, spawning, rearing, and migration.* Above Boulder Creek in the Pilchuck River, the designated

[1] Available at: http://yosemite.epa.gov/r10/water.nsf/Water+Quality+Standards/WQS+Temperature+Guidance/

aquatic life uses to be protected are *char spawning and rearing*. The applicable water quality criteria for these parameters are summarized in Table 5.

> To protect the designated aquatic life uses of "Core Summer Salmonid Habitat," the highest 7-DADMax temperature must not exceed 16°C (60.8°F) more than once every ten years on average.

Special consideration is also required to protect the spawning and incubation season of salmonid species. Where it has been determined that the lower temperatures are necessary to protect spawning and incubation, the following criteria apply:

> Maximum 7-DADMax temperatures of 13 °C (55.4 °F) at the initiation of spawning for salmon and at fry emergence for salmon and trout.

Currently, Chapter 173-201A WAC specifies portions of 7 watersheds in the Columbia River Basin that require these more protective criteria during specified days of the year, (Ecology Publication 06-10-038).

While the criteria apply throughout a water body, there may be site-specific features, including shallow, stagnant, eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason, the standards direct that measurements are taken from well-mixed portions of rivers and streams. For similar reasons, samples are not to be taken from anomalously cold areas such as at discrete points where cold groundwater flow into the water body.

Table 5. Washington State water quality criteria for impaired parameters in the Pilchuck River watershed.

Water Quality Parameter	Use Classification	Criteria
Pilchuck River and all tributaries below Boulder Creek		
Temperature	Core summer salmonid habitat, spawning, rearing, and migration	<16°C 7-DADMax(13°C Feb 15-June 15)[1]
Dissolved Oxygen		>9.5 mg/L 1-DMin[2]
pH		6.5 to 8.5 units[3]
Pilchuck River and all tributaries above Boulder Creek		
Temperature	Char spawning and rearing	<12°C 7-DADMax[1]
Dissolved Oxygen		>9.5 mg/L 1-DMin[2]
pH		6.5 to 8.5 units[3]

1. 7-DADMax means the highest annual running 7-day average of daily maximum temperatures.
2. 1-DMin means the lowest annual daily minimum oxygen concentration occurring in the waterbody.
3. A human-caused variation within the above range of less 0.2 units for pH is acceptable.

Washington State uses the criteria described above to ensure full protection for its designated aquatic life uses. The standards recognize, however, that waters display thermal and oxygen heterogeneity – some are naturally cooler and hold more oxygen, and some are naturally warmer and hold less oxygen. When a water body is naturally warmer than the above-described numeric

Commented [SR(47]: At first, I wanted to say this is not within our study area and omit it let's talk more about that How does including the upper watershed related to Nuri's

Commented [nlm48R47]: Added to our discussion list They listed in the QAPP, but the model is below this In our scenarios we reduce the boundary condition to 16, but we could explore making this closer to 12

Commented [nlm49]: I tried to incorporate additional language to cover oxygen into EPA's temperature language

Commented [LM50]: "naturally cooler" is new criteria, the state limits the allowance for additional warming due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.3 °C (0.54 °F) increase above the naturally warmer temperature condition.

When a water body's DO is lower than the criteria in Table 5 (or within 0.2 mg/L of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the DO of that water body to decrease more than 0.2 mg/L.

This TMDL estimates whether the water body is naturally warmer (or holds less oxygen) or naturally cooler (or holds more oxygen) than the criteria, using a computer model that simulates the physical and atmospheric processes affecting stream temperatures. When a water body does not meet its assigned criteria due to natural climatic or landscape attributes, the standards state that the natural conditions constitute the water quality criteria (WAC 173-201A-260 (1)(a). This provision of the water quality standards is implemented by using the modeled natural condition as the TMDL target.

Only after the allocations in this TMDL are fully implemented or designated uses of the waterbody are being met will Ecology consider a formal rule change to adopt site-specific criteria, as provided by WAC 173-201A-430; at which point, the natural condition, determined by empirical and modeled data, will be used to set new water quality criteria through a public rule-making process.

Commented [LM51]: The standards state that the natural condition provision "constitutes the criteria" under certain conditions What does that mean? Does it mean that the numeric standard is being replaced by the estimated natural condition? One of our stakeholders encouraged Ecology to answer this question very specifically, and here's the answer

Temperature modeling is generally a two-step process. First, the current river temperatures are measured through field monitoring. The watershed's current physical characteristics (e.g., amount of shade provided by the canopy, river geometry, sources of flows, significant cold water flows, point source inputs, etc.) are also recorded. Using this information, a river model is created that simulates current temperature conditions. The model is calibrated by comparing the simulated temperatures with in-stream measurements.

Second, the calibrated model is used to evaluate different scenarios – including a "system thermal potential" or "system potential" scenario that represents the natural condition of the river system. Physical characteristics of the river are changed in the model to simulate the natural condition. Examples of these changes include removing point source discharges, changing the channel geometry to simulate a natural channel, and increasing the riparian shade to represent a natural forest. The model provides a plausible conservative estimate of natural conditions in rivers and streams, especially in the absence of adequate data from non-disturbed reference conditions.

Commented [LM52]: How does "system potential" relate to the natural condition provision in the standards?

The water quality model provides only an estimate of the natural condition temperatures; therefore, a degree of uncertainty is inherent in the model results. Ecology addresses uncertainty in model applications using statistical measure for goodness-of-fit and incorporation of an implicit and explicit margin of safety. Thus, critical conditions that are used for the evaluation of natural conditions incorporate uncertainty in major environmental variables (e.g. stream flows and meteorological conditions).

Commented [LM53]: The discussion of uncertainty is new to the WQStandards section – but is appropriately placed here because the estimate of natural conditions is being used as the target for the TMDL

For this TMDL, Ecology also assessed the uncertainty of the natural condition estimates by assessing the water quality model's sensitivity to the following changes, as discussed in the TMDL Analysis section on "Sensitivity analysis for natural conditions" and illustrated later in this report in Figure xx and Table xx.

(1) cooler headwater and tributary temperatures with more oxygen.
(2) an increase in baseflow
(3) increased system potential vegetation (SPV) height and riparian buffer width.
(4) enhanced hyporheic exchange.
(5) the combined impact of the above four alterations.

Commented [nlm54]: This represents "Supernatural conditions" and has not currently been done for this TMDL Pending further discussion from EPA, it sounds like we will begin to explore more scenarios

To the extent that these (non-discharge) influences on temperature and dissolved oxygen have existed historically, or can be put in place now, these sensitivity analyses provide estimates of the variability associated with the natural condition estimates. This variability should be considered when making future site-specific criteria, impairment, land-use, permitting, or restoration decisions.

Watershed Description

The Pilchuck River watershed is located in Snohomish County, Washington in Water Resource Inventory Area 7 (WRIA 7) (Figure 1). The Pilchuck River watershed is approximately 137 square miles and empties into the Snohomish River, approximately 15 miles above where it enters Puget Sound.

The lower Pilchuck River watershed is made up of primarily low-density residential development and small farms, and includes portions of the cities of Granite Falls, Snohomish, and Lake Stevens.

A large portion of the Upper Pilchuck watershed is forest lands, much of which is managed by the Department of Natural Resources (DNR) (Wright et al, 2001). Within the upper watershed, the area upstream of Menzel Lake Rd (~RM 25.5) is not included in the water quality model or TMDL footprint given resource constraints and the lack of development and sources of pollution upstream of this point.

Commented [MC(55]: Managed how? As state forest land or something else?

Geographic setting

Hydrology and hydrography

The Pilchuck River drainage area is divided into the upper Pilchuck River, the lower Pilchuck River, and the Little Pilchuck Creek watersheds. The Little Pilchuck Creek confluence defines the division between the upper and lower Pilchuck River basins. Little Pilchuck Creek drainage includes Star Creek and Catherine Creek. Tributaries to the Upper Pilchuck River include Purdy Creek, Boulder Creek, Wilson Creek, and Worthy Creek. Tributaries to the Lower Pilchuck River include Dubuque, Bunk Foss, Sexton, and Scott Creeks.

Commented [KH(56]: Should we include a drainage area map to show these watersheds?

Commented [nlm57R56]: Working on it

With an average annual discharge of 364 cubic feet per second (cfs), the Pilchuck River is the largest tributary to the Snohomish River below its confluence with the Skykomish and Snoqualmie Rivers.

Commented [PP(58]: Show these tribs on a map

Commented [nlm59R58]: Figure 1

The hydrology of the Pilchuck River is discussed further in the Results and Discussion section of the report.

Geology

The Pilchuck River watershed is located along the eastern margins of the Puget Lowland geologic region, which consists of a linear depression trending in a north-south direction between the Olympic Mountains to the west and the Cascade Mountains to the east. Along the eastern side of the Puget Lowland in the Cascade foothills, Tertiary- and Cenozoic-aged volcanic and sedimentary rocks (less than 70 million years old) underlie the glacially derived surficial deposits (Bailey, 1998).

The majority of the surficial geologic units consist of "unconsolidated" (non-bedrock) glacial deposits. In the Pilchuck River watershed, Vashon Glacial Till, Younger Alluvium and Recessional Outwash are the primary glacially-derived geologic units (comprising over 88 percent of the watershed). Vashon Glacial Till is a relatively strong, stable geologic material consisting of a mixture of silt, sand, and gravel deposited in front of and below the advancing Vashon glacier. The Younger Alluvium deposits consist of organic rich, stream-laid, clay, silt, and fine sands and lie in and around stream channels. It also encompasses the well-rounded river gravels and cobbles that make up much of the main stem channel bottom. The other significant geologic unit is Recessional Outwash, which consists of well-drained stratified outwash sand and gravel deposits (Bailey, 1998).

Figure 2 illustrates an example of geology in the Pilchuck River valley within the study area.

Figure 4. Vertical cross section of geology at exposed bluff near Russell Road bridge crossing.
Dark gray band in middle is the wetted, top portion of the confining Vashon till layer present throughout the study area.

Land use and land cover

Land use data for the Pilchuck River watershed was obtained from the Snohomish County's Assessor Office as parcel data that has been updated through 2016. These data include 183 land cover types, which were consolidated into 13 categories for analysis purposes (Figure 3).

The single family residential grouped land use makes up a significant area of the lower Pilchuck River watershed, the distribution of detailed County land uses for this category is presented. Vacant area is also a dominant land use category. Comparisons of aerial photos of vacant and open space parcels shows that they are analogous to forested areas, with the County's differentiation between these categories likely related to tax classifications. Therefore, for the remainder of this document, land defined by the County as "vacant" will be referred to as forested.

The Pilchuck River watershed contains large areas of forested land: the largest percent (55 percent) of area in the Pilchuck River watershed is forested (vacant [39.3 percent], managed forest [10.2 percent], and forest [5.4 percent]). Single family residential makes up a sizeable portion of the watershed at 25.4 percent of the area, 91.7 percent of which is single family detached. Areas were calculated from Snohomish County property parcels (Snohomish County Assessor, 2012).

Commented [NE(60]: Add to references

Fish and wildlife

The Pilchuck River and its tributaries support spawning and juvenile Chinook, Coho, Sockeye, Chum, and Pink salmon as well as bull trout and steelhead trout. These native species depend on cool water, pools and riffles, and off-channel wetlands during different parts of their life cycles.

Chinook salmon enter the river as early as mid-August and typically are finished spawning by early October (Savery and Hook, 2003).

The Pilchuck watershed also provides habitat for many animal species, particularly along the riparian corridor and wetlands. Both resident and migratory birds rely on the area for food and raising their young. Many types of mammals, amphibians, and reptiles are abundant in the watershed. Several animals identified as priority species by the Washington Department of Wildlife have been observed in the watersheds, including bald eagles, great blue herons, pileated woodpeckers, red-tailed hawks, cavity-nesting ducks, trumpeter swans, and other waterfowl (French Creek Watershed Management Committee, 2004).

Commented [nlm61]: update?

RSS possibly update a bit here I tended to put more detailed discussion on fish and wildlife needs in the implementation section

Commented [nlm62R61]: Will put on the final combined report to do list

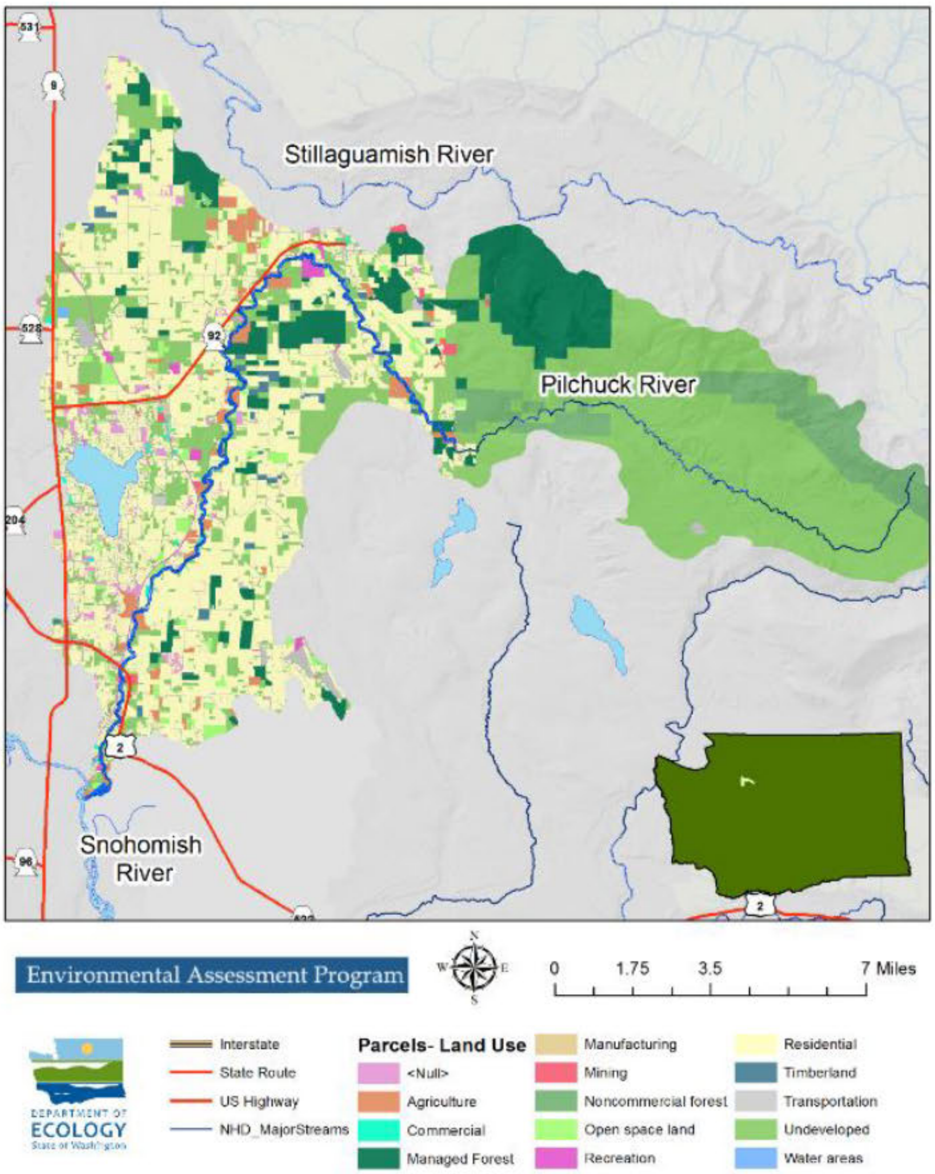

Figure 5. Pilchuck River watershed land use

Commented [PP(63]: It would be great to include the City limits on this map, since you mention it earlier

Commented [nlm64R63]: Added to earlier map I think would make this one a bit too busy

Vegetation

Historically, the Pilchuck River watershed likely consisted of large forested and scrub/shrub wetland areas. Mature and old growth stands of western hemlock and Douglas fir grew on the drier areas and mixed coniferous-deciduous forests in wetter areas (Franklin and Dyrness, 1973). The wetland areas were dominated by hardback spirea.

Currently, the vegetation is mainly red alder, vine maple, black cottonwoods, and western red cedar along the riparian corridor.

Considerable logging has occurred in the watersheds. Some of the cleared land has been replanted; however, much of the area will be or has been developed. Trees in the undeveloped forested areas generally revegetate on their own, but have not reached an old growth stage. These changes in landscape significantly impact the hydrology of the watersheds by increasing the amount of surface runoff and decreasing infiltration.

Commented [PP(65]: Also, research has shown that second growth of 15-20 years age can reduce base flows through transpiration Remember that EAP seminar with the fellow from Oregon?

Commented [nlm66R65]: Can you provide reference This section is another Tetra tech one, that needs work This whole paragraph is unsupported assertions

Commented [SR(67]: Revisit later maybe reorganize sentence order

Commented [nlm68R67]: Agreed

Hydromodifications

Historically, natural wetlands covered much of the western part of the watershed. Extensive wetlands have been documented in the Little Pilchuck Creek basin (Ecology, 1997). In addition, there are several instream man-made structures and culverts in the watershed that are full or partial barriers to upstream fish movement. On the Pilchuck River, these include the City of Snohomish Dam located upstream of the city of Granite Falls and Menzel Lake Road. It should be noted that if flows are high enough, fish can move upstream of the dam (Savery and Hook, 2003).

Commented [nlm69]: from QAPP, reference is too old

RSS if this is the report I am thinking of, we should remove the info reference unless we can get some more specific info on the % coverage and area they are referring to It would be good information and perhaps we can look at historic maps on GIS

Commented [nlm70R69]: Another section that needs work

Commented [PP(71]: levees? Channelization? Loss of floodplain connectivity?

Commented [nlm72R71]: Will work on addressing

Potential sources of contamination

Factors impacting temperature

- **Shade** - Temperature is directly impacted by the amount and quality (height and density) of riparian zone vegetation, which can block solar radiation from reaching the stream surface.
- **Channel geometry** - A river that is wide and shallow will receive more solar radiation compared to a river that is narrow and deep.
- **Groundwater** - Groundwater tends to maintain a constant temperature that can warm a stream in winter and cool it in the summer.
- **Hyporheic flow** - Stream flow that travels through the through the floodplain, gravel bars, or stream sediments and then returns to the stream is known as hyporheic flow. During warm weather, hyporheic flow typically decreases daily maximum temperatures and increases daily minimum temperatures.
- **Heat load** – The temperature of inflows to the river.

Commented [PP(73]: Mention point sources – warm discharges and stormwater runoff from heated pavements or stormwater ponds

Factors impacting DO

Plant Productivity and Respiration

Decreased DO may result from increased nutrient loads that stimulate algae and plant growth, which is referred to as plant productivity. The diurnal (over a 24 hour period) cycle of algal growth increases DO during the daylight hours as the plants perform photosynthesis, but reduces DO levels at night, reaching a minimum around sunrise, as respiration is predominant.

Productivity may be limited by a specific nutrient (usually phosphorus in streams and lakes), by light to fuel photosynthesis, or by retention time in a water body. Increased nutrient loading from anthropogenic sources can enhance algal growth and increase the diurnal DO fluctuation. This can result in lower levels of DO than would have resulted under conditions where humans were absent. Excess nutrients can produce algae in large quantities. While algae can raise DO through photosynthesis when these algae die, decomposition consumes DO, thereby lowering the DO.

Commented [NE(74]: I didn't know plant productivity was affected by retention time Why is that? I don't remember seeing it in QUAL2Kw as a limiting factor

Commented [PP(75]: Expand this discussion to explain CBOD, NBOD, and enhance productivity in one place

Commented [nlm76R75]: added

Biochemical oxygen demand (BOD)

Biochemical oxygen demand (BOD) is the term used to describe the depletion of DO from the water by the oxidation of organic substances. BOD can be either (1) carbonaceous, resulting from the oxidation of carbon-containing compounds such as sugars, or (2) nitrogenous, resulting from the oxidation of nitrogen-containing compounds such as ammonia. The addition of these organic substances to a water body can result in reduced DO content in the water downstream of the pollution source.

Groundwater

Areas of high groundwater input can (in some locations) result in DO levels that are lower than the criteria listed in our state standards. DO in groundwater is generally naturally low to do lack of reaeration (no contact with atmosphere) and oxygen consumption by microbes in the soil and groundwater.

Factors impacting pH levels

Similar to DO, plant productivity also of also affects pH. The pH in streams with high algal productivity typically increases during the daylight hours to its maximum around mid to late afternoon and drops to low levels at night when plants are respiring and releasing carbon dioxide into the water. This diurnal swing can be dramatic enough to increase the daily high and/or decrease the daily low pH of streams and lakes beyond state criteria. These swings are caused by algae and other aquatic plants consuming CO_2 during photosynthesis reducing the amount of CO_2 and bicarbonate in the water. Alkalinity stays essentially constant while pH responds by increasing. This process is exacerbated as more sunlight reaches the stream and as temperatures and nutrient concentrations increase.

Anthropogenic activities can also lower pH. For example, decomposing organic material, such as that found in logging slash.

Natural decomposition in wetlands also can lower pH. The high residence time and high organic matter loading in wetlands, for example, produce low pH and DO levels. Some wetland complexes exist within the study systems and may contribute to the low levels recorded in the mainstem and the tributaries.

In addition, the pH of rain in western Washington is 4.8 to 5.1 (NADP, 2004). Therefore, stormwater and even groundwater may have a low pH due to regional atmospheric deposition rather than local watershed conditions.

Commented [PP(77]: And falling!

Commented [NE(78]: Reference needed

Some streams have a naturally low buffering capacity, which makes them more susceptible to pH changes. These streams can have both low and high pH in the same stretch, though often during different times of the year.

Permitted point sources

Permitted facilities with discharges to a waterbody can potentially be a source of heat, nutrient, or sediment loads.

Permitted facility information was provided from the Ecology Permit and Reporting Information System database. At the time this report was published, there were multiple permitted industrial and municipal wastewater discharges within the Pilchuck River watershed. Table 6 lists the permitted facilities found, while Figure 4 shows the spatial distribution of these facilities. Phase I and Phase II stormwater permits are discussed separately in the following section.

Appendix H (NPDES Facility Analysis) contains more detailed information.

Table 6. Summary of non-stormwater NPDES permits in the Pilchuck TMDL as of spring 2017.

Permit Type	Receiving Waterbody	Permittee Name	Permit #
Municipal NPDES Individual permit IP	Pilchuck River	Granite Falls WWTP	WA0021130
Sand and Gravel General permit	Trib of Pilchuck	Pilchuck Sand & Gravel Inc	WAG503379
	Groundwater	Riverside Sand & Gravel	WAG 503086
	Facility inactive	Granite Falls Quarry L Matheson	WAG503085
	Groundwater	Lake Industries Menzel Lake Gravel	WAG503312
	Unknown	Jaxico Real Estate Investment Group LLC	WAG994258
	Ditch to Little Pilchuck	Thomco Aggregate LLC	WAG503027
	Pond	Premier Pacific Properties (Island Construction Site & Utilities)	WAG503327
	EF Little Pilchuck	Concrete Norwest Getchell Pit	WAG503166
	Pond next to Pilchuck River	D&D Excavating (Marysville Const & Paving Co)	WAG503046

Table 7. Summary of stormwater NPDES permits in the Pilchuck TMDL as of spring 2017.

Stormwater Permit Type	Receiving Waterbody	Permittee Name	Permit #
Construction general permit	Pilchuck Watershed	Numerous; transient	
Industrial general permit	Little Pilchuck	Central Steel	WAR012091
	Little Pilchuck	Northwest Auto Recyclers	WAR303981
	Pilchuck River	UPF Washington LLC (NEPA Pallet & Container)	WAR000752
Municipal general permit	Pilchuck Watershed	Snohomish County- Phase 1	WAR044502
	Pilchuck Watershed	City of Granite Falls- Phase 2	WAR045517
	Pilchuck Watershed	City of Lake Stevens- Phase 2	WAR0021130
	Pilchuck Watershed	City of Snohomish- Phase 2	
Transportation general permit	Pilchuck Watershed	WSDOT	WAR043000

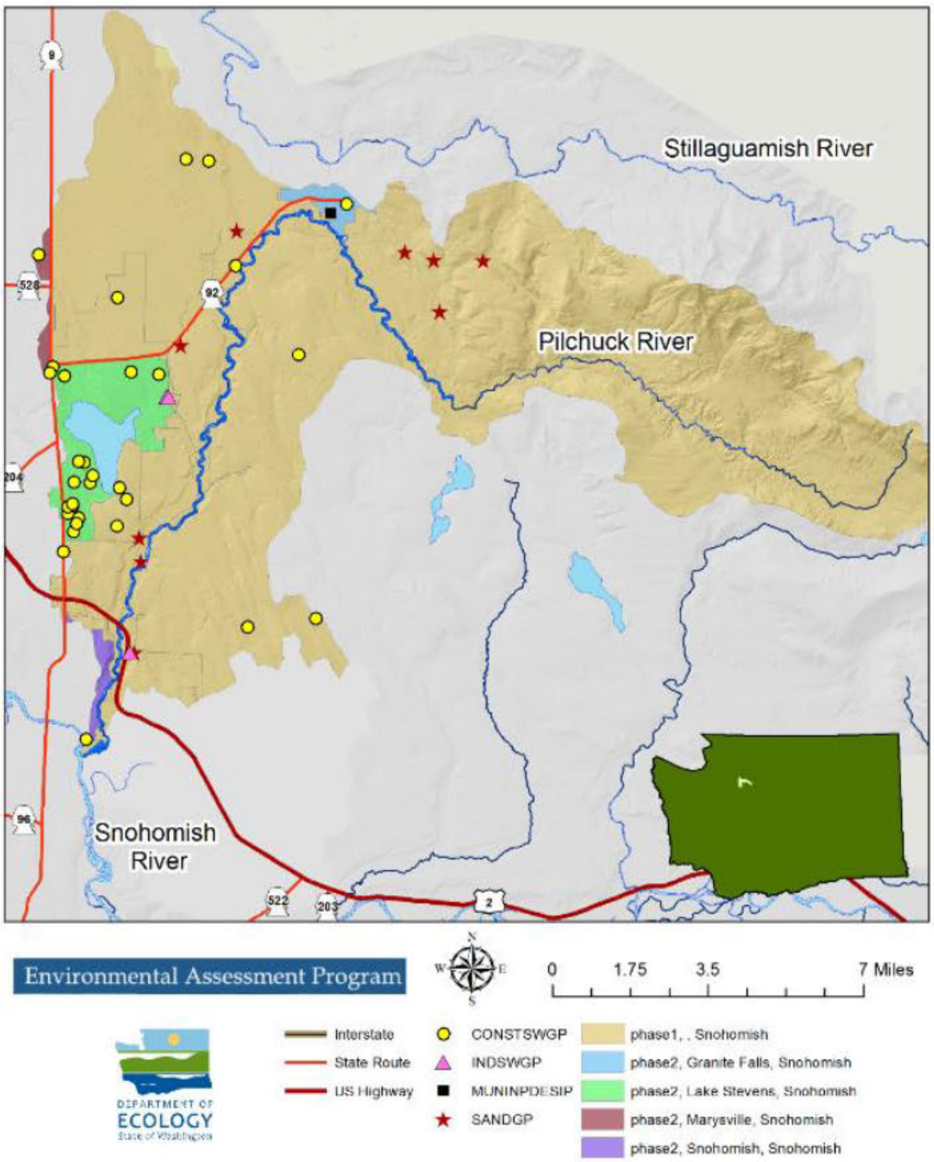

Figure 6. Permitted facility locations and WSDOT stormwater (state routes) within the Pilchuck River watershed

Commented [NE(79]: I see that the river line color and width changes, maybe add to legend Is this the upper/lower river boundary? Label this or perhaps show the watershed boundary for upper vs lower?

Commented [nlm80R79]: Noted; will fix as time allows

Commented [NE(81]: Is there a way to define CONSTSWGP, INDSWGP, MUNINPDESIP, and SANDGP? Perhaps add a heading that reads "Permit Type" using paint program?

Commented [nlm82R81]: Noted; will fix as time allows

Commented [MC(83]: Need to change legend titles for phase1 and phase2 to phase I and phase II, to be consistent with the text (and less confusing)

Commented [nlm84R83]: Noted; will fix as time allows

Commented [PP(85]: WSDOT stormwater?

Commented [nlm86R85]: Added to caption; will consider better fix as time allows

Granite Falls WWTP

The City of Granite Falls operates an oxidation ditch wastewater treatment plant that discharges to the Pilchuck River (Ecology, 2015a). Ecology issued the current permit for this facility on April 15, 2015, and it expires on April 30, 2020.

Secondary treated and disinfected effluent flows into the Pilchuck River through an outfall diffuser section buried approximately one foot below the bottom of the river bed (Ecology, 2015a). The diffuser is over 16 feet long, which is greater than 25% of the river width at low flow. Ecology concluded that this discharge meets the requirements for an exception to the rule that the mixing zone must occupy less than 25% of the river width.

The average temperature of the effluent is 18°C with a maximum of 22.6°C, based on discrete measurements collected between noon and 3pm (data from April 2010 to September 2014). The average and maximum ortho-phosphate concentrations of 8 samples were 2,520 and 4,850 ug/L respectively, which was slightly higher than the average and maximum for Total Phosphorus (Ecology 2015a). These results suggest that most of the phosphorus in the effluent is typically in a dissolved form, with very little particulate phosphorus.

General Sand and Gravel Permit

The Sand and Gravel General Permit regulates discharges of process water, stormwater, and water from mine dewatering into waters of the state associated with sand and gravel operations, rock quarries, and similar mining operations. The permit also covers concrete batch operations and hot mix asphalt operations. Untreated discharge water from sand and gravel operations may harm fish, aquatic life, and water quality.

Ecology reissued the Sand and Gravel General Permit on February 17, 2016. Ecology received one appeal on the reissued Sand and Gravel General Permit. The reissued permit became effective on April 1, 2016.

Both stormwater and process water from sand and gravel operations can be a source of suspended solids, which in turn can have attached phosphorus. Suspended solids may be generated from (Ecology, 2015b):

- Washing, screening, or crushing rock
- Stripping and digging operations
- Seepage from working face
- Stormwater run-on and runoff from disturbed areas
- Runoff from overburden, waste piles, and stockpiles
- Dust suppression
- Processing wastes

The most common types of permit violations for sand and gravel permittees are pH, turbidity, and nitrate-nitrite (Ecology, 2015b).

General Construction Stormwater Permit

Construction site operators are required to be covered by a Construction Stormwater General Permit if they are engaged in clearing, grading, and excavating activities that disturb one or more acres and discharge stormwater to surface waters of the state. Smaller sites may also require coverage if they are part of a larger common plan of development that will ultimately disturb one acre or more. Operators of regulated construction sites are required to:

- Develop stormwater pollution prevention plans.
- Implement sediment, erosion, and pollution prevention control measures.
- Obtain coverage under this permit.

The current permit was appealed and a settlement agreement was reached for a minor permit modification. The Final CSWGP Modification with a Response to Comments was issued on March 22, 2017. Proposed changes went into effect May 5, 2017.

General Industrial Stormwater Permit

This statewide permit applies to facilities conducting industrial activities that discharge stormwater to a surface waterbody or to a storm sewer system that drains to a surface waterbody.

Ecology reissued the Industrial Stormwater General Permit on December 3, 2014
The Industrial Stormwater General Permit (ISGP) became effective on January 2, 2015.

Municipal Stormwater Permits

During rain events, rainwater washes the surface of the pavement, rooftops, and other impervious surfaces. This stormwater runoff accumulates and transports pollutants and contaminants via stormwater drains to receiving waters and can degrade water quality. Ecology issues NPDES permits to larger entities that operate municipal separate storm sewer systems (MS4s) making them responsible for collecting, treating, and discharging stormwater to local streams and rivers.

Two types of municipal stormwater permits exist in this watershed: Phase I and Phase II. Phase I permittees are cities and counties that operate large and medium MS4s.

The Phase II Municipal Stormwater Permit rule extends the coverage of the National Pollutant Discharge Elimination System (NPDES) program to certain "small" municipal separate stormwater sewer systems (MS4s). The Department of Ecology used maps of the census urbanized areas and jurisdictional boundaries to identify Phase II jurisdictions. Ecology issued two Phase II permits: one for Eastern Washington and one for Western Washington.

Snohomish County and the Washington State Department of Transportation (WSDOT) hold Phase I MS4 permits in the watershed. In addition, four communities (the cities of Granite Falls, Lake Stevens, Marysville, and Snohomish) hold Phase II MS4 permits.

Phase I permits regulate stormwater discharges to waters of Washington State from the permittees' MS4s in compliance with Washington Water Pollution Control Law (Chapter 90.48 RCW) and the federal Clean Water Act (Title 33 USC, Section 1251 et seq.).

The EPA phase II regulations went into effect in early 2003 and apply to all regulated small municipal separate storm sewer systems. Ecology first issued the Western Washington Phase II permit in 2007 and modified it in 2009. Ecology reissued it unmodified on August 1, 2012 to be effective through July 31, 2013. At the same time, Ecology also reissued an updated 2013 to 2018 permit on August 1, 2012. The current version of the permit, as modified in December 2014, went into effect as of January 16, 2015.

Ecology's five-volume Stormwater Management Manual is available on the internet at www.ecy.wa.gov/programs/wq/stormwater/manual.html. The current version is the 2012 manual as amended in 2014.

Under the Phase II permit, cities must follow prescribed guidelines to manage stormwater before it discharges to surface water. Permit requirements fall under five basic categories: public education and outreach, public involvement and participation, illicit discharge detection and elimination, the control of runoff from development, and pollution prevention. General information on the Phase II permit is available at www.ecy.wa.gov/programs/wq/stormwater/municipal/phaseIIww/wwphiipermit html.

Snohomish County (Phase I Permittee)

On August 1, 2012, Ecology issued an updated 2013-2018 Phase I MS4 Permit that became effective on August 1, 2013. The permit was first modified on December 17, 2014 and the first modification went into effect on January 16, 2015. The permit was modified a second time on July 20, 2016 and the second modification went into effect on August 19, 2016.

Snohomish County has a Stormwater Management Plan (2017) that outlines the county's responsibilities to protect water through stormwater management. The Plan can be found at https://snohomishcountywa.gov/ArchiveCenter/ViewFile/Item/4667

More information on Phase I permits and Snohomish County can be found at www.ecy.wa.gov/programs/wq/stormwater/municipal/phaseIpermit/phipermit html or www.ecy.wa.gov/programs/wq/stormwater/municipal/Phase1equivalentstormwatermanualsWestern.html

Washington State Department of Transportation (WSDOT) (Phase I Permittee)

Ecology issued a new modified NPDES permit to the WSDOT on March 6, 2014. This permit addresses stormwater discharges from WSDOT MS4s in areas covered by the Phase I Municipal Stormwater Permit, the Eastern Washington Phase II Municipal Stormwater Permit, and the Western Washington Phase II Municipal Stormwater permit. WSDOT highways, maintenance facilities, rest areas, park and ride lots, and ferry terminals are covered by this permit when a WSDOT-owned MS4 conveys the discharges. State highways in the Pilchuck River watersheds include state route (SR) 2, SR 9, SR 522, SR 204, and SR 92.

More information on the WSDOT permit can be found at
www.ecy.wa.gov/programs/wq/stormwater/municipal/wsdot.html

WSDOT has a 2014 Highway Runoff Manual that provides tools for designing stormwater collection, conveyance, and treatment systems for transportation-related facilities. This manual has been approved by Ecology as functionally equivalent to the Stormwater Management Manual for Western Washington and is available at
http://www.wsdot.wa.gov/Environment/WaterQuality/Runoff/HighwayRunoffManual htm#Draft

Cities of Granite Falls, Marysville, Lake Stevens, and Snohomish (Phase II Permittees)

The Phase II permit for western Washington covers at least 80 cities and portions of five counties with an effective date of September 1, 2012. The updated 2013-2018 permit became effective on August 1, 2013.

Outside of the city boundaries, Snohomish County must follow Phase I of the NPDES municipal stormwater guidelines to manage stormwater before it discharges to surface water.

Nonpoint sources

Nonpoint pollution sources are dispersed and not controlled through discharge permits. Potential nonpoint sources within the Pilchuck River watersheds include:

Runoff sources

- *Soil erosion* from agricultural fields and residential areas can carry nutrients to streams, especially if fertilizers are applied in excess of what the plants can utilize.
- *Manure* that is spread over fields during certain times of the year can enter streams via surface runoff or fluctuating water levels.
- *Livestock in riparian area* can increase nutrient delivery where manure is deposited in the riparian area. Fluctuating water levels and surface runoff can wash nutrients into the water, which can be further exacerbated by constant trampling which loosens soil, delivering both the soil and absorbed nutrients to the water.
- *Pet waste* concentrated in public parks or private residences can be a source of contamination, particularly in urban areas.

Non-runoff sources

- *Inadequate riparian shade* due to removal of riparian zone vegetation that blocks solar radiation reaching the stream surface. A loss of shade also increases algal productivity.
- *Residential, commercial, or industrial wastewater* (non-permitted) piped directly to waterways or may have malfunctioning on-site septic systems where effluent seeps to nearby waterways.
- *Livestock with direct access* to water can deposit nutrients in their waste directly to the stream.

Commented [NE(87]: This makes it sound like there's a single Phase II permit that covers 80 cities, but above it sounds like these cities each hold individual permits Reconcile

Commented [nlm88R87]: Just one permit, but different permit numbers, will try to clarify

Commented [SR(89]: This is all good info but we are again in the situation where the implementation plan may need to repeat it as corrective actions are discussed Not sure right now how to best address this We might think about a table and reserve/move the text to the implementation section

Commented [nlm90R89]: Fine with moving whatever we need to implementation section

- *Tile drains*, installed primarily in agricultural areas to drain shallow groundwater, may contribute nutrients.
- *Unnatural bank erosion* due to land use activities, channelization, stream straightening, and riparian vegetation removal, deposits soils into the streams. These soils typically carry nutrients.Other/natural sources of nutrients and BOD

Wildlife are a potential source of BOD and nutrients, but are considered a "natural background" source unless human activities have either concentrated the discharge of their wastes or caused a significant population increase resulting in higher nutrient loadings. Open fields, lawns, riparian areas, and wetlands provide feeding and roosting grounds for some birds whose waste products can increase BOD and nutrients in runoff.

Commented [nlm91]: Expand if time to include
Wetlands
Hyporheic Zone
Groundwater
Weathering of geology

Goals and Objectives

Project goal

Commented [NE(92]: Above you stated "a TMDL is the sum of the wasteload and load allocations, any margin of safety, and any reserve capacity The TMDL must be equal to or less than the loading capacity" Should any of these items be mentioned here specifically or does the WQIR / IP cover that?

The goal of this water quality improvement report and implementation plan is to address temperature and DO problems in the Pilchuck River in order to improve water quality and restore beneficial uses. More specifically, the goal is for the Pilchuck River to meet Washington State DO and pH water quality standards.

Project objectives

Data collection objectives

- Collect high quality data during field surveys from June to September 2012.
- Refine understanding of Pilchuck River through follow-up data collection efforts in 2014 and 2016.
- Characterize stream temperatures and processes governing the thermal regime in the Pilchuck River and major tributaries. This includes the influence of tributaries and groundwater/surface water interactions on the heat budget.

TMDL analysis objectives

- Develop a predictive temperature model for the Pilchuck River. Using critical conditions in the model, determine the streams' capacities to assimilate or release heat. Evaluate the system potential temperature (approximate natural temperature conditions).
- Characterize processes governing DO and pH in the Pilchuck River and major tributaries, including the influence of tributaries, point and nonpoint sources, and groundwater.
- Develop a model to simulate instream biochemical processes and productivity, DO, and pH in the Pilchuck River. Evaluate system potential conditions with the model by removing human pollutant sources and hydromodifications to the extent feasible.
- Using critical conditions in the model, determine the loading capacity of pollutants needed to meet temperature, pH, and DO water quality criteria and protect beneficial uses.
- Present potential pollutant allocation scenario for point and nonpoint sources in order to meet the loading capacity.
- Use the calibrated models to evaluate scenarios for future water quality management of the Pilchuck River watershed.

Implementation objectives

Methods

Ecology's study design, data collection, and data quality methods are described in detail in the Quality Assurance Project Plan (QAPP) for this study (Swanson et al., 2012) and addendums to the QAPP (Mathieu, 2014; Mathieu, 2016).

Final study area, locations, data quality, data collection, and modeling methods are described briefly here and in greater detail in Appendices C, D, and E.

Study area and locations

Commented [SR(93]: Somewhere we should put a map showing river miles Anywhere we discuss processes with relation to river miles the reader will likely want to refer to that map

The study area for this project extends from approximately river mile (RM) 25.5 between Menzel Lake Rd and the Snohomish diversion dam to ~RM 1.5 at the 2nd St bridge in Snohomish (Figure 6).

Commented [PP(94]: Show these landmarks on your map

Ecology collected samples and measurements from 14 key locations on the mainstem Pilchuck River, 1 point source (2 locations), and 2 significant tributaries (Table 8). Appendix C details additional locations that were sampled in a more limited capacity for the TMDL including 5 additional mainstem sites, 17 minor tributaries, 9 seeps, and 5 piezometers.

Table 8. Core study locations on the Pilchuck River.

Commented [NE(95]: A column showing river miles would be helpful reference for understanding location of point sources and tribs Not so much for this figure itself, but for reference as reader progresses through report

Commented [NE(96]: Lat/long are included in Table C-1, you could drop here if you need the space

Location ID	Map#	Location Description	Latitude	Longitude
Mainstem Pilchuck				
07-PIL-25.5	1	Pilchuck River at Menzel Lake Rd., ~20 ft. d/s of bridge	48.01872	-121.91504
07-PIL-21.5	2	Pilchuck River at Robe-Menzel Rd., just u/s of bridge	48.05479	-121.95703
07-PIL-18.9	3	Pilchuck River ~200 ft upstream of Granite Falls WWTP outfall	48.07601	-121.97758
07-PIL-18.7	4	Pilchuck River at WDFW access at end of Ray Gray Rd	48.07632	-121.98303
07-PIL-15.1	5	Pilchuck River at 64th St., ~100 ft. u/s of bridge near RB [3]	48.05355	-122.02357
07-PIL-11.6	6	Pilchuck River just u/s of 28th Pl NE access to river	48.02309	-122.02401
07-PIL-10.4	7	Pilchuck River at Russell Rd., ~30 ft. u/s of bridge	48.00740	-122.03333
07-PIL-8.6	8	Pilchuck River u/s of confluence with Little Pilchuck River	47.98907	-122.03681
07-PIL-8.5	9	Pilchuck River at OK Mill Rd., ~25 ft. d/s of bridge	47.98675	-122.03550
07-PIL-8.2	10	Pilchuck River ~1,000 ft d/s of OK Mill Rd	47.98498	-122.03672
07-PIL-5.8	11	Pilchuck River ~900 ft u/s of Dubuque Rd; u/s of spring/ trib on left bank	47.96309	-122.06328
07-PIL-5.7	12	Pilchuck River at Dubuque Rd., ~150 ft. d/s of bridge	47.96207	-122.06569
07-PIL-3.6	13	Pilchuck River at Three Lakes Rd, ~25 ft. u/s of bridge	47.93756	-122.07466
07-PIL-2.0	14	Pilchuck River at 6th St., ~80 ft. u/s of bridge	47.91883	-122.08253
Point Sources and Major Tributaries				
07-GRA-EFF	P1	Granite Falls WWTP effluent at plant after UV treatment	48.07899	-121.97520

Commented [NE(97]: Missing info

07-GRA-STP	P2	Granite Falls WWTP manhole near outfall to Pilchuck	48.07605	-121.97971
07-DUB-0.0	T1	Dubuque Creek ~50 ft. u/s of confluence with Pilchuck R	47.98791	-122.03630
07-LIT-1.8	T2	Little Pilchuck Creek at 12th St., ~200 ft. d/s of bridge	48.00707	-122.04557

1 d/s ≡ down stream
2 u/s ≡ up stream
3 RB ≡ right bank.

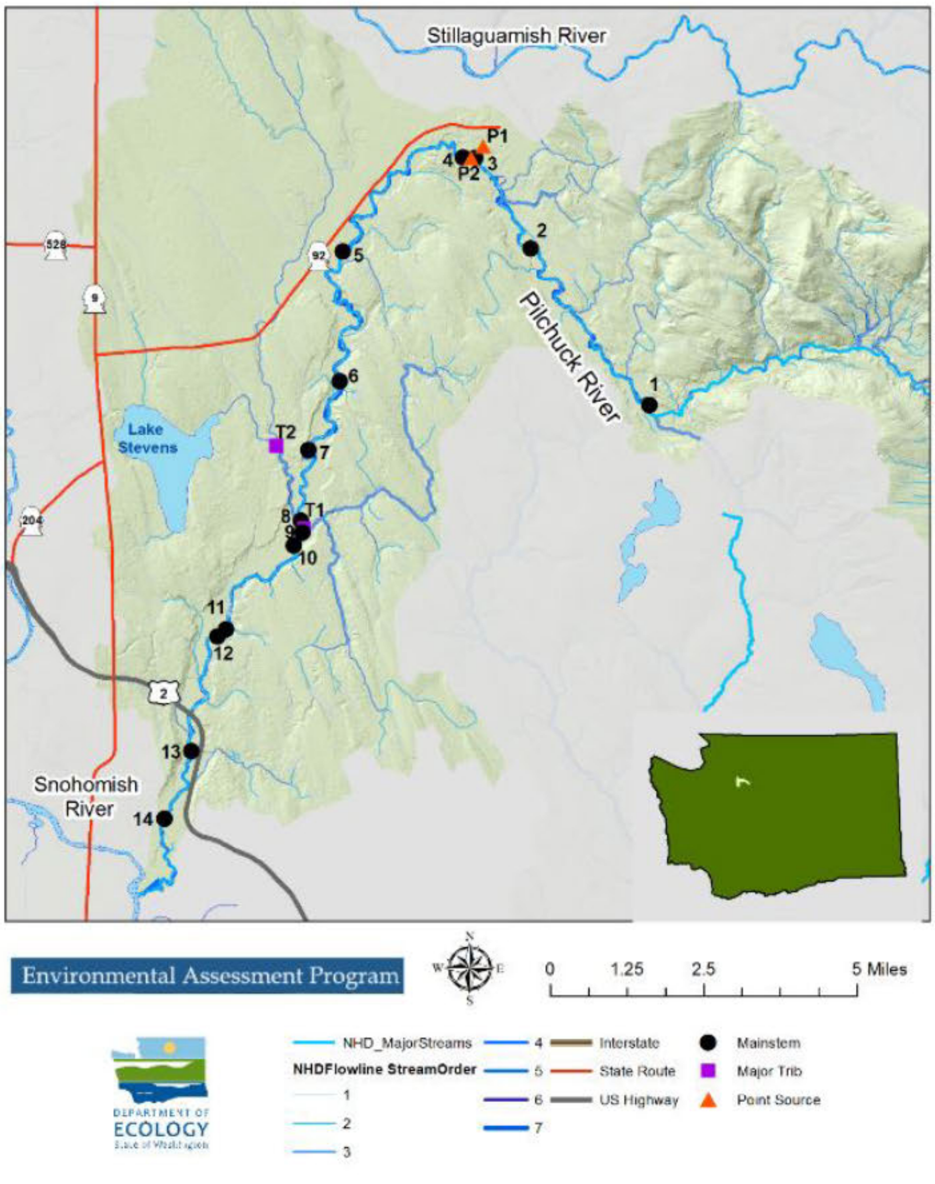

Figure 7. Pilchuck TMDL study area and locations.

Commented [NE(98]: The isolated stream south of Pilchuck River really draws attention

Consider connecting and labelling this stream, and also Pilchuck River above station #1 Also consider labelling Dubuque Creek and little Pilchuck River on this map

Label shaded area as representing watershed boundary

Commented [PP(99]: Label the tribs you sampled and the landmarks that mark the boundaries of the study

Commented [SR(100]: Add to legend (or somewhere) something that makes it clearer that black dot, magenta square, and orange triangle are monitoring points

Data quality methods

Data quality assurance methods included:

- Field Quality Assurance (QA) Methods:
    - Duplicate samples, streamflow, periphyton, and water quality measurements.
    - Calibration of water quality instruments (including sondes and thermistors), prior to use or deployment, using NIST-certified standards and manufacturer or Ecology procedures. Deployed sondes were also post-checked using the same procedures.
- Lab QA Methods:
    - Manchester analyzed duplicates, blanks, matrix spikes, and laboratory control samples for each batch of samples analyzed, following routine laboratory procedures (MEL 2008).

See Appendix D for further information on data quality.

Data collection methods

In general, data collection followed the plan outlined in the QAPP and addendums, with a few notable exceptions:

- During the 2012 study, several thermistors were lost or stolen. As a result several locations did not have complete temperature records from June to October. These stations were redeployed in early August and captured the 7-DADMax peak for the year, but not the peak daily max.
- The 2016 study planned to install 8-12 piezometers along the course of the river. Piezometer installation was attempted at multiple locations in the upper watershed, but failed due to underlying glacial till, cobbles, or bedrock. As a result, only five piezometers were successfully installed in the mid to lower river. Additional seeps were sampled to compensate for the reduced number of groundwater samples.

Information and data from sources outside of Ecology

Information from the USGS flow gage 12155300 (Pilchuck River near Snohomish, WA) was used for the model development and calibration, as well as general validation of Ecology data. Streamflow and stage data were utilized from the USGS station (USGS, 2017).

Commented [NE(101]: Where is this flow gage on the map? Consider including in Figure 6

Modeling framework

Ecology used the recently updated QUAL2Kw 6.0 modeling framework (Pelletier and Chapra, 2008) to develop the loading capacity for nutrients and temperature and to make predictions about water quality under various scenarios. The QUAL2Kw model framework and complete documentation are available at http://www.ecy.wa.gov/programs/eap/models.html.

Appendix E describes the modeling framework in greater detail. In general Ecology:

- Used the TTools extension for ArcView (Ecology, 2015) to process GIS data for input to the shade model.
- Used Ecology's Shade xlsm model (version 40b04a06; Pelletier, 2015) to estimate effective shade along the mainstem of the Pilchuck River.
- Collected/compiled time series data and developed time series records from discrete data using linear interpolation or regression.
- Populated the QUAL2Kw model with channel geometry, model segmentation, and reach information.
- Populated the QUAL2Kw model with meteorology, water quality, and shade data.

Figure 9 depicts a conceptual diagram of the modeling inputs and framework.

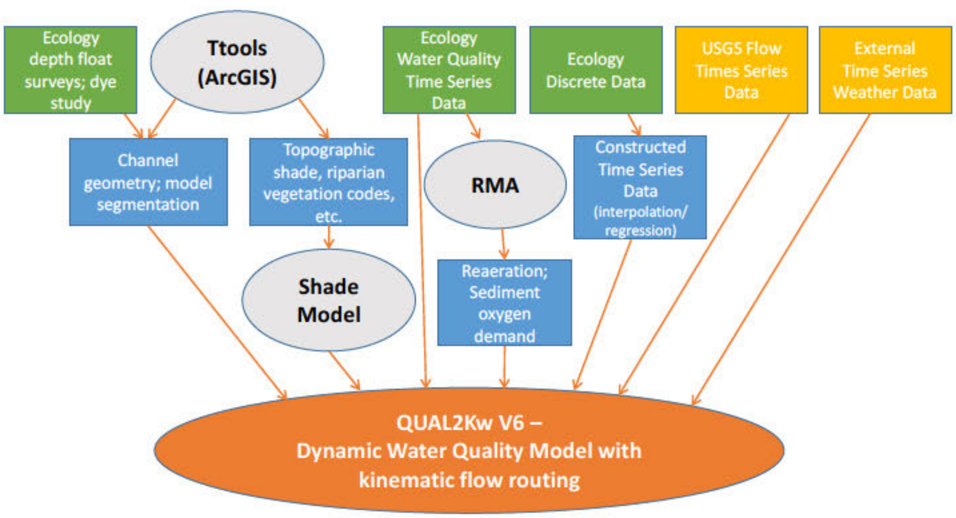

Figure 8. Conceptual diagram of the model inputs and framework.

The QUAL2Kw water quality model was first developed for the temperature analysis and then expanded to simulate the effects of nutrients, periphyton growth, carbonaceous biochemical oxygen demand, and hyporheic biofilm growth on DO in the Pilchuck River.

Commented [PP(102]: This is the first you mentioned this Somewhere earlier in the report provide some background to explain why this needed to be included in the model

There are several important concepts for modeling the effect of primary productivity in running waters. Among the most important are:

1. Within the model, only one nutrient can limit algal growth at a time. The limiting nutrient will be the least available relative to its demand. This principle is known as Liebig's law of the minimum (Chapra, 1997).
2. For river modeling, it is important to correctly limit the growth rate to predict algal biomass yield. The growth rate is limited by the concentration of the most limiting nutrient (i.e., the supply rate of the limiting nutrient), by the amount of available light, and by temperature. In some situations other factors limit growth instead of nutrients, such as scour or sloughing, space available for attachment, or grazing by macroinvertebrates.
3. It is appropriate to use the dissolved-fraction concentration of the limiting nutrient, such as Soluble Reactive Phosphorus (SRP) and Dissolved Inorganic Nitrogen (DIN), as the basis for modeling periphyton growth. This is because the nutrient must be in a readily-available form for biological uptake and growth to occur during solute transport (Jacoby and Welch, 2004).
4. Total phosphorus and nitrogen are important to model since the particulate and organic fractions can be transformed into the dissolved fractions through various instream and hyporheic processes.

Commented [KH(103]: A little unclear with the word choice I think you mean how concentrated the most limiting nutrient becomes, in other words, the amount of concentration?

Ecology's River Metabolism Analyzer (RMA) was also used to derive estimates of respiration, productivity, reaeration, and sediment oxygen demand (SOD) using the diel water quality data and whole stream metabolism analysis techniques.

Detailed documentation of the modeling framework is provided in Appendix E (Model Documentation).

Model calibration methods

Appendix E (*Model Documentation*) provides a detailed description of the model calibration. The general approach was:

1. Evaluating the quality of the geometry rating curves, and associated longitudinal depth and width data, by comparing to observed time of travel data within the QUAL2Kw model.
2. Calibrating to observed temperature data by making several adjustments to rates, constants, and input data, based on review of the data quality and adjustment of light and heat model parameters.
3. Using continuous temperature data from all stations in the 2012 study to evaluate the balance of error between sites and minimize overall bias.
4. Using the calibrated temperature model (QUAL2Kw) as a starting point for DO and nutrients.
5. Calibrating to observed suspended solids data by adjusting the Inorganic Suspended Solids (ISS) and chlorophyll input data to optimize goodness of fit to observed data during critical conditions. While DO in the model was generally insensitive to the concentrations of these parameters, having realistic levels in the model is important to accurately account for light limitation factors.
6. Calibrating productivity of the hyporheic biofilm to generate a SOD comparable to estimates derived from whole stream metabolism analysis using RMA. The diffuse/groundwater CBOD input concentrations were increased to match this level of productivity.
7. Researching rates used in calibrated QUAL2Kw models in the Western U.S. and using the 25^{th} and 75^{th} percentiles of these rates as the ranges for the initial adjustment of model parameters. A couple rates were ultimately adjusted beyond this interquartile, but remained within the bounds of literature and previous studies.
8. Relying on diel DO data collected during the late August 2012 survey as the primary tool for visual evaluation during calibration of DO. Data from this survey was generally of higher quality, had more stations, and was collected during more stable flow conditions then the late July/early August 2012 survey.
9. Using additional nutrient and diel water quality data from 2016 to help guide calibration.

Commented [MC(104]: Same as above What rates? Can we state the specific rates that were adjusted rather than the generic term "a couple rates"?

Results and Discussion

During the 2012 field study, Ecology collected flow, DO, pH, temperature, periphyton, and nutrient data. The goal of this effort was to characterize and model the response of temperature, DO, and pH in the water column. Ecology extended the study during the summers of 2014 and 2016, by collecting additional data and groundwater samples in order to calibrate the model and fully understand groundwater input and instream processes.

Commented [MC(105]: Should state which parameters we collected additional data for I don't think it was all of them (At least I don't remember collecting periphyton)

Complete data tables and graphics for the project are located in Appendix C.

Commented [NE(106]: You mention in the section above on "data collection" that additional seeps were sampled to make up for missing piezometers, but I don't see that data in Appendix C Not sure what you did or if it's relevant to include, but thought I'd mention

Was any data besides water temp collected at piezometers (pH/chem/etc) that needs to be in App C?

Commented [nlm107R106]: Forgot to amend these Will add

Data quality assurance results

Ecology sources

In 2004, Washington State enacted a law entitled the Water Quality Data Act. The law requires that the data used in certain water quality activities meet its credible data principles. As required by this law, Ecology developed a policy regarding the use and collection of water quality data. The three main goals of the policy are to:

1. Explain how data is used to inform decisions about water quality and water quality improvement projects,
2. Describe criteria to establish data credibility, and
3. Recommend appropriate training and experience for data collection.

Ecology's policy: "Ensuring Credible Data for Water Quality Management" is available online at: http://www.ecy.wa.gov/programs/wq/qa/wqp01-11-ch2_final090506.pdf.

Overall, Ecology found the study data to be of acceptable quality and useable based on the above policy and the study objectives. Some results were qualified or rejected based on failure to meet measurement quality objectives or other issues. Appendix D provides more detailed data quality results.

Commented [PP(108]: You don't use qualified data? Maybe two separate statements, such as "use of qualified data will be limited to purposes appropriate to the level of quality Rejected data will not be used "

Sources outside of Ecology

Commented [NE(109]: Meteorological data?

Ecology reviewed the data quality methods and results from USGS and determined the data used was of acceptable quality. A description of USGS data quality methods and results is included in Appendix D.

Model quality assessment results

Appendix E provides a detailed description of the model quality evaluation including an error and sensitivity analysis.

In general the calibrated model performed well for temperature under a dynamic set of conditions over the course of the modeling period. Performance was measured by the ability to predict important spatial and temporal patterns of these variables.

Performance was also assessed through goodness of fit to observed data, via statistics for error and bias. In this respect, the model calibration was comparable in fitness to similar applications of QUAL2Kw (Sanderson and Pickett, 2014):

Commented [PP(110]: Provide a graph illustrating calibration

- For all hourly predictions during the most critical period of 7/8/12 to 9/8/12:
    - Average RMSE = 0.65°C
    - Average Bias = -0.10°C
    - Error was worst during early July (higher flows) and early September (lower temperatures).
- For observed vs predicted 7-DADMax values from 7/8/12 to 9/8/12:
    - Average RMSE = 0.46°C
    - Average Bias = -0.02°C

The temperature model was most sensitive to factors affecting either:

a) Solar shortwave radiation, including observed (or modeled) solar radiation and effective shade and cloud cover inputs.
b) Longwave radiation, which is influenced by the chosen emissivity model.

The calibrated model also performed well for key water quality variables including DO, pH, and nutrients, under a dynamic set of conditions over the course of the modeling period. Performance was measured by the ability to predict important spatial and temporal patterns of these variables, particularly diel DO at higher levels of primary productivity.

Performance was also assessed through goodness of fit to observed data using statistics for error and bias. In this respect, the model calibration was comparable in fitness to similar applications of QUAL2Kw(Sanderson and Pickett, 2014), with an average RMSE of 0.23 mg/L and an average bias of 0.02 mg/L, during the most critical period of 7/8/12 to 9/8/12.

Commented [PP(111]: Provide a graph illustrating calibration

The model was most sensitive to parameters and inputs that affect bottom algae primary productivity and biomass, particularly maximum growth rate and respiration rates.

Hydrology

Based on USGS gage data, streamflow in the Pilchuck River followed a relatively typical pattern (near historical median for 1992-2016) in August and early September of 2012, but were well above the median in June and July and below the median in late September and October (Figure 7). Flows steadily receded from July through September, dropping to a baseflow of 50 to 70 cfs. Streamflow levels were above the median from June through mid-August and then below the median in September and early October. Data collection also occurred in 2014 and 2016, which were more typical flow years (near median flow).

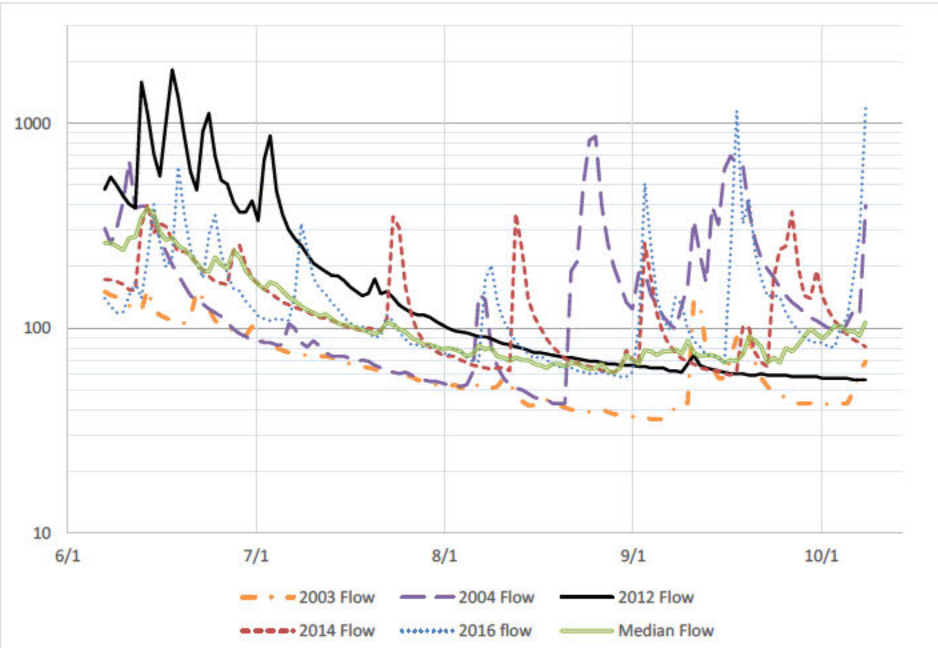

Figure 9. Pilchuck River summer flows for study years, a low-flow year (2003), and historical median daily flow.

The most significant hydrologic inputs to the Pilchuck River within the study area are groundwater (see discussion below), Little Pilchuck River, and Dubuque Creek. These two tributaries range from a combined input of 0.1 cfs (or 0.2 % of mainstem flow) in the late summer or early fall of 2014 to 14 cfs (or 14% of mainstem) in July 2012.

Flow measurements at the USGS gage only extend back to 1992, so a long term flow record was not available to determine reliable flow statistics. Based on the 25-year record from 1992 to 2016, the 7Q10 low flow is ~41.8 cfs and the 7Q2 low flow is ~57.6 cfs. Low-flow years depicted in Figure 7 include 2003 (the lowest annual 7-day flow on record) and 2004 (7-day low flow closest to 7Q10).

Groundwater and Cold Water Refuge

Groundwater

Commented [NE(112]: are the spikes in flow due to precipitation? Looks like 2012 had lower precip, worth mentioning?

Commented [PP(113]: That is a pretty short record – it can result in some distortions from short-term trends Going back to 70s or earlier is better How does it compare to the Stilly or some nearby gage with a longer record? It would help to make your case for your 7Q10 being reasonable and 2003 a "critical flow" year

Commented [PP(114]: Which was ?

Commented [MC(115]: Do we need to explain that the peaks are flow increases related to storm events?

The localized effect of groundwater entering a waterbody can significantly affect water quality and the associated fish habitat. Ecology area observed numerous locations in the study area (Figures 9 and 12) where the following types of subsurface discharge occurred:

Commented [MC(116]: Why not 9 and 10? No reference to Figure 12 in later portions of this section

- **Lateral discharge from shallow surficial aquifers** to the mainstem Pilchuck or hydrologically connected tributary can occur when an underlying confining layer prevents vertical migration of groundwater. This type of discharge was observed throughout the watershed and typically occurred where the river channel intersected or was adjacent to a confining Vashon till layer. A similar type of discharge was observed in an area where an intersection with confining bedrock resulted in concentrated groundwater discharge near the outfall to the Granite Falls WWTP and WDFW access at Ray Gray Rd.

- **Vertical upwelling of groundwater** occurs when groundwater enters the river in a relatively porous area of a streambed. Ecology observed this condition in the piezometer downstream of Dubuque Rd. It is unclear whether the source of this upwelling water was a break in the confining layer and connection to a deeper aquifer unit or a thicker layer of alluvium that was connected to the surficial aquifer layer (i.e., depth to Vashon till was greater). Water quality results, temperature monitoring, and vertical hydraulic gradients suggest this was not shallow or recent hyporheic discharge (for example from a riffle/pool sequence or gravel bar in the active channel).

- **Off-stream wetlands, ponds, lakes, or tributaries** can have a hydrologic subsurface connection with the Pilchuck River channel. Based on aerial photography and digital elevation models there are numerous areas where this is a possibility. Notable wetlands, ponds, and lake areas include the pond wetland complexes at ~RM13, the Connor Lake tributary, and ~RM25. Notable tributary channels with potential subsurface flow are Little Pilchuck and Dubuque creeks.

- **Alluvial floodplain aquifers (hyporheic flow)** can have locations where stream flows go subsurface then return to the river as cooler water. The time water spends subsurface and the distance it travels can be very short or very long, affecting the amount of cooling that occurs. Areas where this may occur include the major side channel at RM 14. These areas were identified by springs and seeps with conductivities similar to river water. More discussion on the effect of hyporheic flows on river DO and temperature levels is provided in the following section of this report.

Ecology developed multiple flow balances based on seepage surveys conducted in 2012 and 2014 (Table 12). An uncertainty analysis was performed on the seepage flow balance for each reach. The reach seepage gain or loss was deemed significant if it exceeded the 95% confidence interval of the combined measurement error for each flow site.

The net significant gain was calculated as the sum of all significant gains and losses (bold numbers in Table 9), while "net gain – all" is the sum of all gains and losses, including those that were not statistically significant.

The majority of the surveys showed a consistent significant overall gain of approximately 8 to 14 cfs, equating to roughly 10 to 20% of river flow. A large "gain" (a positive difference from upstream to downstream) of 45 cfs was measured during the July 2012 survey when flows were above 100 cfs. However, only five mainstem measurement locations were surveyed and boundary flows were dropping over the course of the survey. This suggests that this difference may be partially due to dynamic flow changes.

Table 9. Flow gains and losses, with significance, from the 2012 and 2014 seepage surveys.

Date	Flow gains/losses in cubic feet per second								Net Significant Gain	Net Gain - All
	RM 20.9	RM 18.7	RM 15.1	RM 10.4	RM 8.6	RM 8.4	RM 5.7	RM 2		
7/31/12	nm	nm	22.88	-5.6	nm	13.8	nm	8.22	44.9	39.3
8/28/12	nm	nm	4.73	-0.73	nm	3.84	5.27	-1.52	13.84	11.59
7/9/14	2.3	10.58	-5.98	-6.3	nm	8.39	3.05	1.29	9.74	13.33
8/7/14	0.7	4.35	3.25	nm	4.59	1.09	-3.61	0.57	8.94	10.94
8/28/14	-3.81	17.4	-10.12	-1.54	nm	4.85	-0.14	1.69	8.32	8.33
significant gain		not significant				Median =			9.74	11.59
significant loss		nm = no measurement								

The 2014 surveys identified two areas of consistent and substantial gains:

1. The reach between Robe-Menzel Rd (PIL20.9) and Ray Gray Rd (PIL18.7).
   a. As mentioned above, groundwater discharge was observed at the bedrock outcropping near the Granite Falls WWTP.
   b. In 2010, Snohomish County documented a 0.9°C decrease in 7-DADMax temperature between ~RM 20.6 and ~RM 18.5 (SCSWM, 2012).
2. The reach between Russell Rd (PIL10.1) and OK Mill Rd (PIL8.4).
   a. Given that the mouths of Little Pilchuck River and Dubuque Creek enter in this stretch, it is possible that the two tributaries are contributing significant subsurface flow to the Pilchuck River at lower flows.
   b. The 8/7/14 seepage survey suggested much of this gain was happening before the confluence of the two tributaries; however, seepage was observed along the right bank just upstream of the Little Pilchuck, which parallels the mainstem in this stretch, indicating a possible subsurface connection prior to the confluence.

Cold Water Refuges

Ecology also looked for seeps, small tributaries, and made other observations during the 2014 and 2016 surveys to identify areas that could potentially serve as cold water refuges (CWR) (Table 13). Measured temperatures in these seeps and tributaries ranged from 9.8 to 17.1°C (14.2°C average) and were between 2.7 and 13.1°C cooler than the adjacent mainstem temperature (5.6°C average).

Commented [PP(117]: Per mile? The "nm" values suggest that the difference represents different reach lengths on different surveys If you didn't standardize it to reach length, then this table is comparing oranges to kumquats to tangerines
Also, perhaps add 8 6 to 8 4, put the value in the 8 4 column, and delete the 8 6 column That would make the values more consistent
And the consistent negative values at 10 4 and the nm on 8/7/2014 might make the value at 8 6 an underestimate compared to the other surveys

Commented [SR(118]: Not clear to me how we can document a gain if the immediate upstream station was not measured

Commented [NE(119]: I can't tell if this is supposed to support your conclusion that much of this gain was happening before the confluence or not If it's supporting it, consider using "for example" instead of "however"

Commented [PP(120]: Explain what you mean by "could potentially serve" Do you mean that the temperatures are right for a CWR but the fish usage needs to be confirmed? "Potentially" could either mean they would be CWRs if they were restored, or they might be CWRs with fish right now but we don't know for sure
Suggestion: add a paragraph earlier that explains what you mean by CWR EPA defines it simply by temperature If you set a definition for your work here, you can say they are definitely CWRs But it would be good to discuss the idea that the cold water is there, but there is still a need to determine if the fish are using them
I can ask my EPA contacts about terminology if you want There should be some way to differentiate between a cold patch defined by temperature, and a CWR where fish use is documented

RSS Paul has really complicated things here but he makes a good point We want to suggest that it could be an existing refuge but also that the area might also have the potential for enhancement of CWR size

Longitudinal temperature profiles collected in 2014 were not as useful as field surveys in identifying CWR because short term cooling effects were generally limited to less than 0.2°C in the main channel. Significant reductions in temperature were only observed in poorly mixed or off-channel locations which were not measured by these profiles. Profiles were collected during the 2014 floats with temperature recorded every 30 seconds.

Many of these potential cold water refuge locations appear to currently lack the channel structure, or habitat features to adequately provide refuge to fish. This information along with extensive habitat information provided by Snohomish County's Middle Pilchuck River Assessment Habitat Report (SCSWM, 2012) should be used to prioritize potential instream restoration projects

Commented [SR(121]: Let's revisit this sentence later if we do this in the implementation plan then let's refer the reader to what we did, not what we should do

Commented [PP(122]: This paragraph should be expanded and explained more Fish use of CWRs is an emerging question for this issue What information do you have about that?
What areas would you want to restore? Which areas already have robust CWRs and should be protected, rather than restored? Which current CWR areas could provide better ecosystem services if enhanced or restored? Are there areas that don't currently have CWRs but could have them if restored?

Table 10. Potential Coldwater Refuge locations identified in the Pilchuck River

Site ID	~RM	Bank	Temp (°C)	Diff from mainstem temp (°C)	Description/comments
Seep23.1	23.1	Right	10.8	-7.2	Large log jam and pools immediately upstream
Tr b22.5	22.5	Right	12.5	-5.4	Tr butary with some large woody debris (LWD) and side channels
Seep21.1	21.1	Right	16.43	-2.7	xx
Seep20.5	20.5	Right	12.48	-5.2	Near Skinner road side channel monitored by Snohomish County
Tr b19.6	19.6	Right	17.1	-3.5	Tr butary with pools, log jams, braids, and seeps within 0.5 km
Seep18.9	18.9	Left	13.9	-6.4	Groundwater seep upstream of WWTP outfall
Seep18.1	18.1	Right	14.68	-3.6	Seep on bank ~10' above water surface
Tr b17.2	17.2	Left	15.1	-1.8	Tr butary with pools, log jams, and seeps within 0.5 km
Seep15.3	15.3	Left	13.49	-7.1	Seep; possibly fed by upland wetlands ~500' to NE
Tr b15.3	15.3	Left	15.39	-3.8	Tr butary; poss bly fed by upland wetlands ~500' to NE
Seep15.1	15.1	Right	17.5	-2.9	Off channel wetlands likely fed by groundwater and hyporheic flow
Seep14.3	14.3	Right	14.9	-5.7	Series of three culverts in armored bank
Side Channel	14.3	Left			Major side channel
Seep13.3	13.3	Left	15	-6.1	Multiple seeps from RM 12.8 to 13.5; off channel habitat potential
Seep11.7	11.7	Left	12	-10.5	Off channel habitat potential, needs LWD/cover
Seep10.7	10.7	Left	14.66	-8.3	Multiple seeps, I kely fed by large wetlands complex to E/SE
Tr b10.6	10.6	Left	9.81	-13.1	Tr butary, likely fed by groundwater and wetlands complex to E/SE
Tr b7.3	7.3	Left	12.21	-4.9	Tr butary channel/culvert and multiple seeps
Tr b6	6.0	Left	13.86	-4.5	Tr butary channel fed by wetlands to the east
Seep5.8	5.8	Left	14.9	-5.6	Seep just upstream of Dubuque Rd
Average =			**14.2**	**-5.6**	

Commented [SR(123]: Thanks for taking such great notes and geolocating all the seep locations Nuri!!! I do not remember you making such good additional notes!

RSS Heather it might be good to put your GIS skills to use and look at the adjacent land use/presence of wetlands, etc and guide readers to understand how to assess an area for potential CWR creation We might also spend some time in the implementation text talking about the different ways to create CWRs

RSS Nuri, didn't we try and make some flow estimates at some locations? I seem to remember finding blades of grass to do that! Heather and I might combine a little discussion of temp differences and flow rates in the implementation plan

Commented [NE(124]: Are these temps averages of 2012 and 2014 surveys? What month were these temps measured (can describe in text)

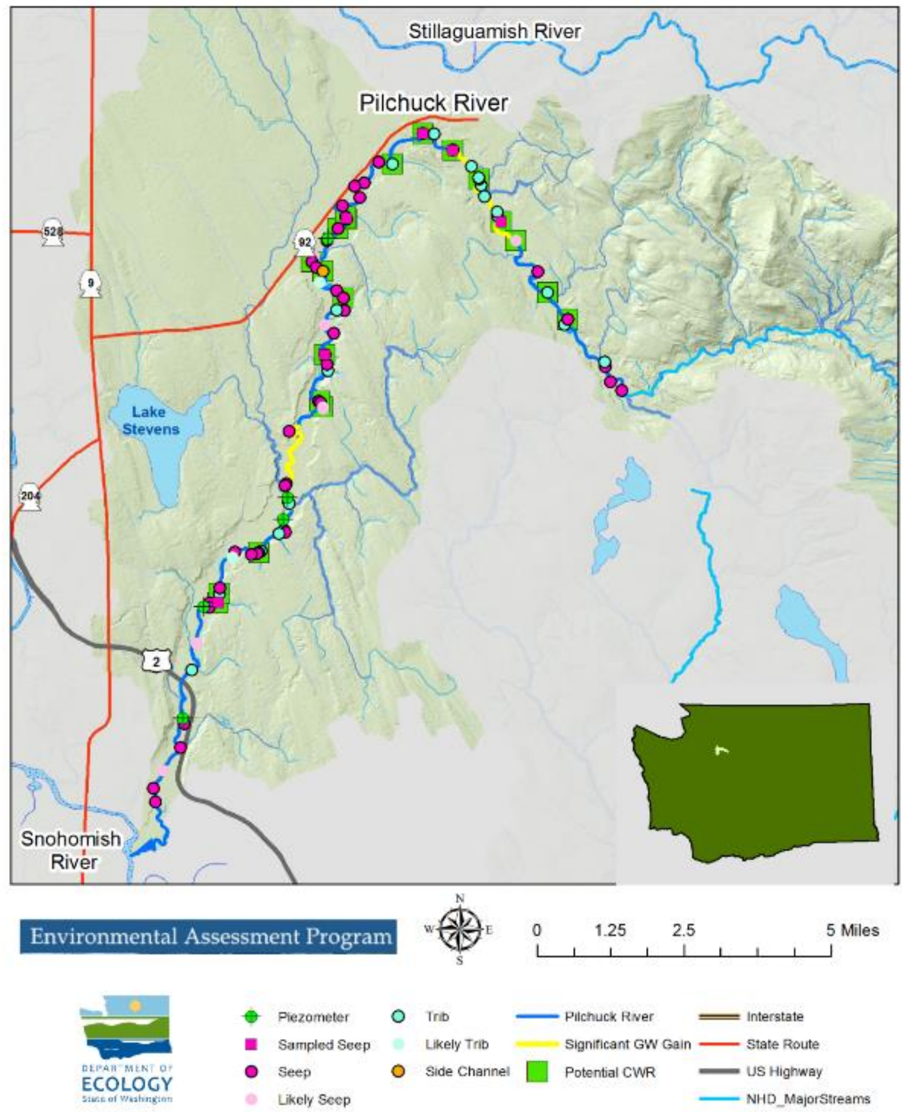

Figure 10. Locations of observed and sampled seeps, piezometers, potential cold water refuge (CWR), and reaches with significant flow gains.

Field staff also collected water quality measurements of apparent groundwater seepage during surveys conducted in 2014 and 2016 (Figure 10). Given that measurements were collected from day-lighted sources, the temperature, pH, and DO results are likely higher than subsurface groundwater.

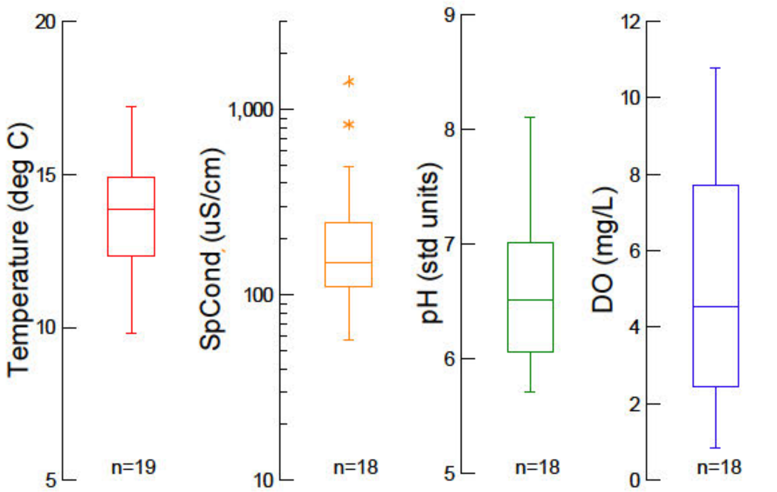

Figure 11. Boxplots of groundwater seep measurement results for 2014 and 2016.

In 2016, the mainstem river bottom was instrumented with 5 in-stream piezometers to measure groundwater characteristics at or just below the river bed. Four of the piezometers were instrumented with temperature loggers at multiple depths and deployed in the river for a period of two months. The other piezometer was installed at 64th Ave bridge (PIL15.1) and only left in for one day and then sampled, due to impending site access restriction related to removal and replacement of the existing bridge. This piezometer did not have any temperature logger installed.

Based on positive vertical hydraulic gradients, water quality characteristics, and temperature profiles, Ecology identified the 64th Ave bridge (PIL15.1) and Dubuque Rd (PIL5.7) piezometers as likely areas where the river was gaining flow. The remaining piezometers upstream of Little Pilchuck (PIL8.6), downstream of OK Mill Rd (PIL8.2), and at Three Lakes Rd (PIL3.6) were identified as likely losing.

Commented [SR(125]: No time now, but let's compare this to the Table 12 results for consistency

Temperature results for the piezometers are depicted in Figure 11. The gaining piezometer at Dubuque Rd shows a relatively stable, cool temperature of ~13°C at the lowest temperature logger (~3.5 feet below streambed). In the other 3 piezometers temperatures below the streambed mimic stream temperature patterns, but daily variations are muted at deeper depths. As an example, on 9/10/16 the daily max temperature ~1 foot below the streambed was 2 to 2.5°C less than the stream temperature, highlighting the potential importance of the hyporheic zone in regulating stream temperatures.

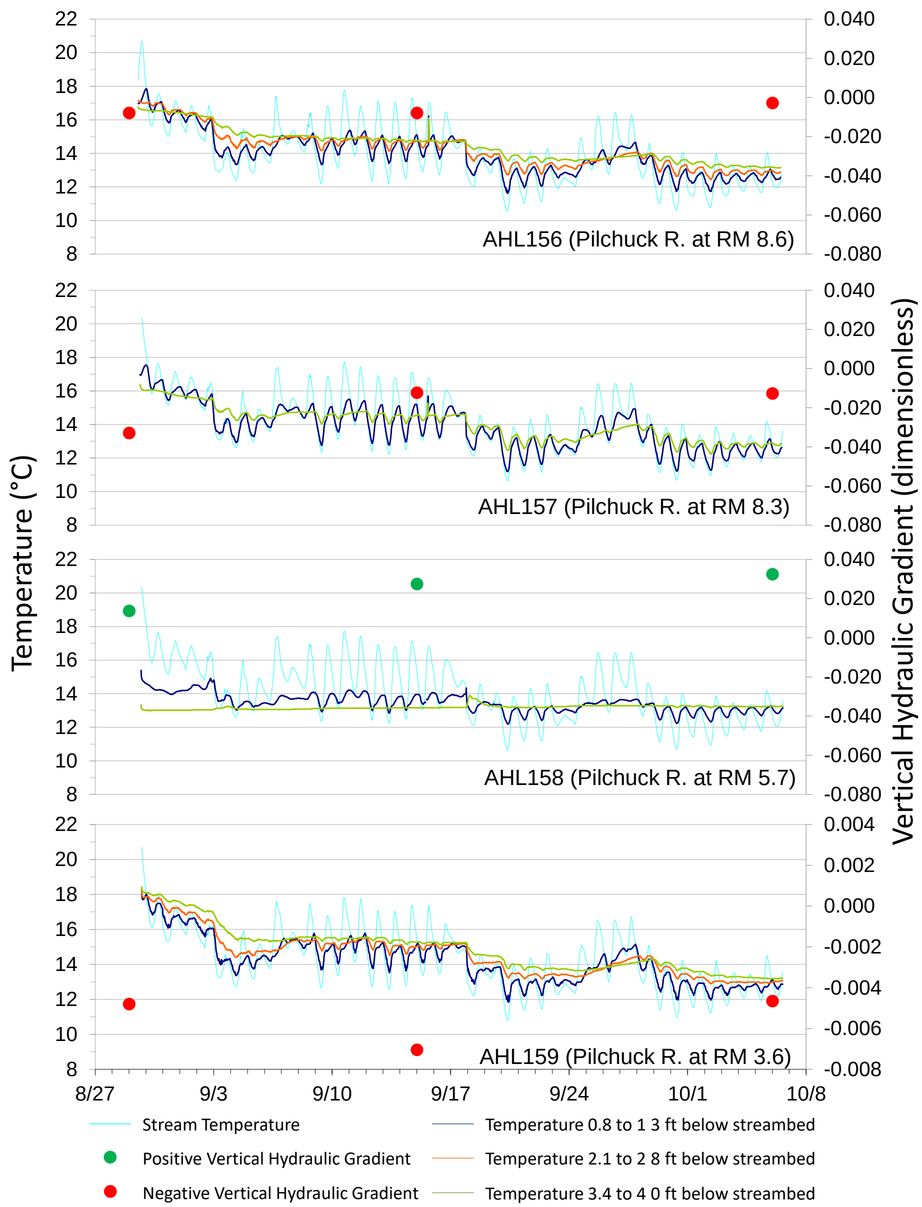

Figure 12. Piezometer temperature monitoring results for 2016.

Figure 13. Selected groundwater seepage areas observed within the Pilchuck River channel during 2014 surveys.

Commented [MC(126]: It would be beneficial to have a short description in the text about what each photograph is showing

Hyporheic zone

The hyporheic zone of a stream refers to the saturated interstitial spaces below the stream bed and adjacent stream banks that contain some proportion of channel water (White, 1993). It plays an important role in buffering stream temperatures, providing habitat, cycling nutrients, and buffering pollutants. Hyporheic areas have been described as "giant trickling filters" (Danielopol, 1989).

xxx

Biological productivity within the hyporheic zone can be a significant contributor to whole-stream productivity (Mulholland et al, 1997; Fellows et al, 2001) and affect both localized and overall dissolved oxygen levels. Even systems with significant primary productivity from aquatic plant life can be net-heterotrophic due to hyporheic activity (Grimm and Fisher, 1984). Streams with hyporheic productivity tend to be net sinks for organic matter and dissolved oxygen (Mulholland et al, 2001) due to the presence and growth of heterotrophic organisms (invertebrates and microbes).

The hyporheic zone can be either a net source (from decomposition of particulate organic matter) or a net sink (due to microbial assimilation) of dissolved organic carbon (DOC) (Brugger et al 2001; Battin et al., 2003; Crenshaw et al, 2002). Forest/riparian soils in the floodplain terrace can represent a significant source of DOC to the hyporheic zone (Clinton et al, 2002; Mei et al, 2012).

The potential for several different hyporheic exchange processes were observed in the Pilchuck River during the study (Figure 14), including:

- Downwelling/upwelling flow in riffle/pool sequences with coarse alluvial substrate. Downwelling typically occurs at the beginning of a riffle, with upwelling occurring in the downstream pool. This is most prevalent in the upper and mid sections of the study area.
- Flow through large alluvial deposits (gravel/sand bars or islands) in the active channel. This type of hyporheic flow was observed throughout the study area.
- Flow through alluvial floodplain aquifers (historic river channel) adjacent to active stream channel. This is most prevalent in the middle to lower sections of the study area.

Figure 13 demonstrates the model simulated effect of hyporheic flow on predicted daily maximum temperatures for the Pilchuck River on August 5, 2012. Without hyporheic flow, temperatures would increase by up to 0.9°C and an average of 0.4°C. A large increase in the hyporheic zone thickness (to 100 cm) and flow fraction (to 25%) would decrease daily max temperature by up to 1.0°C and an average of 0.6°C.

Modeling analysis also found that the current level of hyporheic activity provides up to an 18% and an average of 8% decrease in inorganic phosphorus concentrations in the river (compared to no hyporheic activity).

Commented [SR(127]: Would be good to add some text on temp benefits Torgensen et al has a great photo we might be able to use that shows small fish utilizing cool water inputs along gravelly edge habitat No time to dig it up now Another case where I am wondering where we balance what goes in the tech report/study section and what is better suited to the implementation section Nuri I am glad you are so aware and involved in thinking about implementation now to strike the balance on where things go in this larger document

Commented [SR(128]: Nuri can you add a little for the reader on why DOC is important? I am not well read on what role it plays

Commented [NE(129]: Consider moving this paragraph and figure to the TMDL Analysis section, because you have not yet discussed the model

Commented [SR(130]: This I find fascinating but it also generates questions How is hyporheic flow related to groundwater as a whole? Is it fraction of groundwater and if so how was that %age calculated?

Commented [SR(131]: Might the hyporheic cooling be greater in some areas than others? How was the effect modeled/calculated?

Commented [nlm132]: However, this is does decrease DO to some extent, but perhaps can be viewed as natural heterotrophic productivity?

RSS if we had natural levels of nutrients I would say yes If we have elevated levels of nutrients then it seems we would have elevated levels of heterotrophic productivity

Commented [PP(133R132]: Based on the definition of "natural" in our standards, you would have to ask if the hyporheic zone has been modified by human activity, and what would it look like absent human disturbance? "Natural" DO uptake in the hyporheic zone would occur with a "natural" channel in a watershed with a "natural" sediment, water, nutrient, and carbon regime

Commented [NE(134]: Belongs in separate paragraph I think

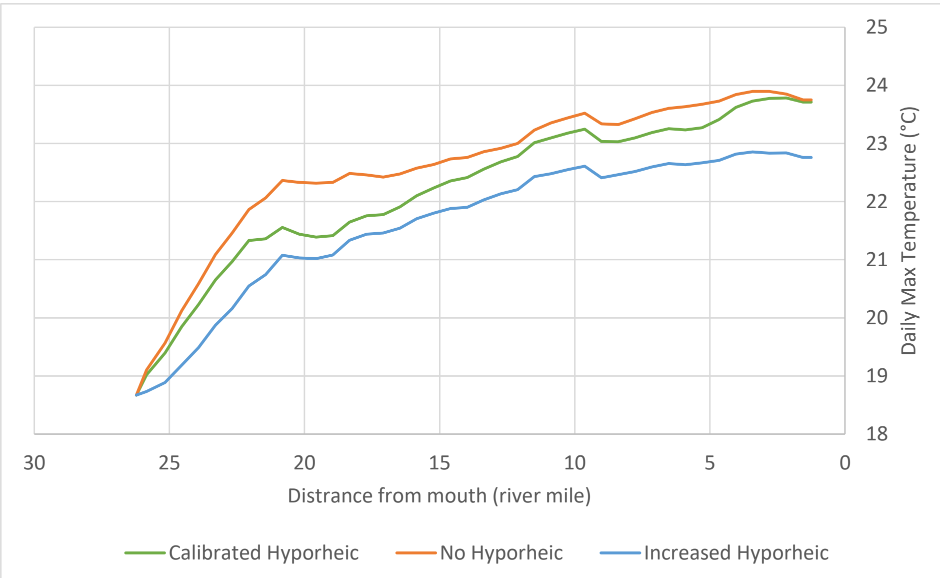

Figure 14. Model simulated effect of hyporheic flow on Pilchuck River daily maximum temperatures for 8/5/12.

Figure 15. Examples of observed hyporheic flow in the Pilchuck River.

Commented [SR(135]: Should we explain to the reader what the processes shown depict? Text about suggests it might

Meteorology

Hourly air temperature, humidity, wind speed, solar radiation, and cloud cover data were used from the locations identified in Table 10. In addition to these stations, Ecology installed a network of data loggers to continuously monitor near-stream air temperature at 11 stations in 2012.

The AgWeatherNet station at Snohomish and the National Weather Service site at the Everett Paine Field Airport provided the primary sources of dew point, solar radiation, wind, and cloud cover data.

Table 11. Weather data used in the 2012 model.

Agency	Station	Frequency	Air Temp	Dew Point/RH	Solar Rad	Wind	Cloud Cover
	07-PIL-2.0		X				
	07-PIL-5.7		X				
	07-PIL-8.5		X				
	07-PIL-10.4		X				
	07-PIL-15.1		X				
	07-PIL-21.5		X				
	07-PIL-25.5		X				
	07-CON-0.0		X				
	07-DUB-0.0		X				
	07-LIT-1.8		X				
WSU AgWeatherNet	Snohomish	15 minute	X	X	X	X	
WA Ecology	05A105	15 minute	X				
NCDC Coop SOD	Monroe 455525	Daily	X				

Commented [NE(136]: What is this station? Does it need to be included in Table C-1

Agency	Station	Frequency	Air Temp	Dew Point/RH	Solar Rad	Wind	Cloud Cover
NCDC Surface Airways	Arlington Municipal Airport	Hourly	X	X	X	X	X
	Everett Snohomish Airport		X	X	X	X	X

NCDC = National Climatic Data Center
SOD = Summary of the Day

After reviewing monitoring stations in the vicinity of the Pilchuck River watershed, the National Climate Data Center (NCDC) Cooperative Summary of the Day station, MONROE 455525 was selected as the closest station with a long period of record (50+ years) for calculating a distribution of annual hottest 7-day period air temperatures. Distribution of the highest annual 7-DADMax values from this station is shown in Table 11. Also shown are the values of the individual annual hottest 7-day periods within the last decade. Shading in the table helps distinguish the relative difference between the recent years. Year 2012 has one of the highest annual hottest 7-day periods on record, falling out around the 98^{th}-99^{th} percentile.

Table 12. Summary of air temperature data at MONROE 1948 -2012.

Percentile	Highest Annual 7-day Mean of Daily Maximum*		Year	Highest Annual 7-day Mean of Daily Maximum*	
0%	63.6		2002	67.1	
10%	65.5		2003	69.3	
20%	67.0		2004	71.6	
30%	68.1		2005	67.5	
40%	68.9		2006	73.1	
50%	69.4		2007	69.8	
60%	69.9		2008	71.1	
70%	70.9		2009	76.4	

Commented [NE(137]: For readability/ plain talk, suggest you put the most important information at the beginning of each paragraph (your main point), then follow it up with all the supporting information It's hard to find the main point in this paragraph because it's the last sentence (global)

Commented [MC(138]: No footnote to table

Commented [NE(139]: Having these two different tables aligned with the same number of rows is really confusing at first Consider eliminating the table on the left, and adding columns on the right table identifying the percentile of years 2002-2012, and possibly the rank (for example, "3rd warmest")

Shading is not defined and doesn't match between these two tables, consider removing it

Commented [PP(140]: ? show units in table

80%	71.6		2010	82.9	
90%	74.3		2011	79.3	
100%	82.9		2012	81.7	

Effective shade

Effective shade is measured as the difference between solar radiation above the canopy and the solar radiation that ends up making it to the stream.

Effective shade produced from riparian vegetation and topographic features was estimated using the Shade model. The model quantifies the solar radiation received along each reach of the channel for each hour of the day, taking into account shading provided by vegetation canopy and topographic features.

Effective shade estimates the Shade model were checked using hemispherical photography. Hemispherical canopy pictures were taken at or near each water temperature monitoring location along the mainstem of Pilchuck River. Ecology processed the images using both HemiView and Gap Light Analyzer (GLA) software (Frazer et al., 1999) to provide field estimates of effective shade to compare to the shade model results. The HemiView and GLA calculations were made for August 14, 2012 to represent critical conditions (peak 7-DADMax).

Figure 15 illustrates an effective shade profile for August 15, 2012. Effective shade ranged from near 0% to greater than 90%, but was typically less than 50% (between 10% and 40%).

Commented [NE(141]: Suggest that heading sentence in paragraph should state the point you want to make about Figure 8, rather than just stating that it shows data from MONROE Make your point right away if possible

Commented [NE(142]: Is it worth explaining why you used two different pieces of software?

Alternatively, do you need to present both software results if you're not going to compare them?

Totally your call on that, I'm just not sure including both results adds useful information for the reader here and may cause some confusion

Maybe just mention that both gave similar results or something like that?

Commented [MC(143]: Or August 2014?

Commented [NE(144]: Why is the date on the plot different (Aug 14 vs Aug 15)

Is this the date of photography? If so, it would be better to state that Little confusing

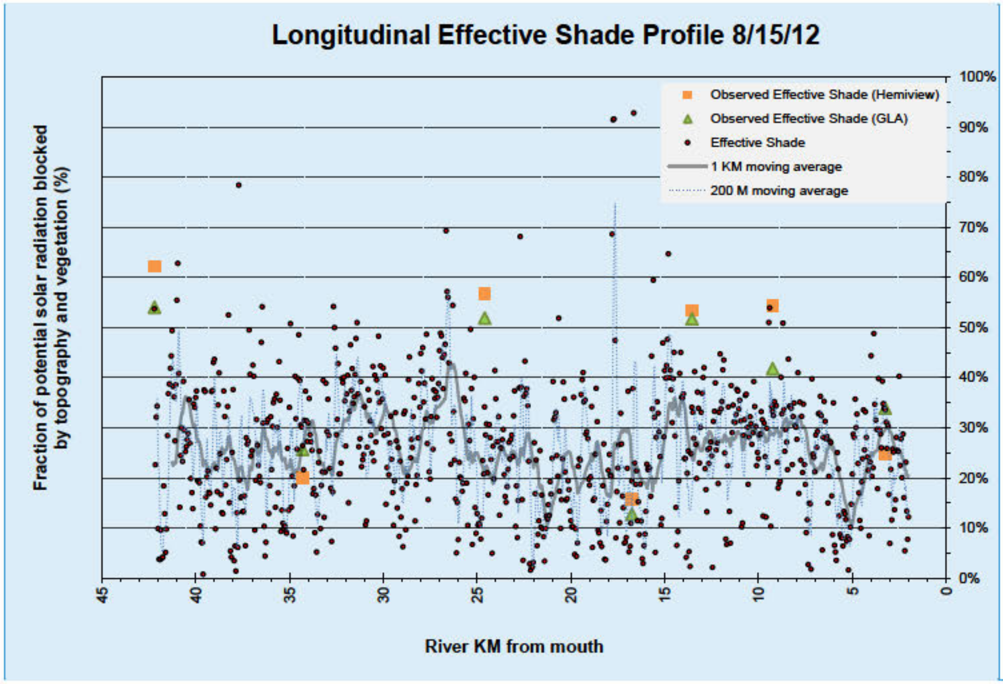

Figure 16. Modeled effective shade along the Pilchuck River for Existing Vegetation on 8/15/12.

Water temperature

Ecology monitored water temperature in 2012 using data loggers at numerous sites along the Pilchuck River mainstem, and at key tributaries. Table 14 summarizes the peak daily max and 7-day average daily max (7-DADMax) values at these sites. The peak 7-DADMax (22.05°C) and daily max (22.87°C) temperatures were recorded at the Russell Rd site (PIL10.4) on August 14 and August

Commented [NE(145]: y-axis title should be next to the labels I think

Do you feel that the higher (>50% effective shade) observed values are representative of the stream? They seem to stand out as higher than either moving average

Commented [SR(146]: Do we want to report temp to a hundredth of a degree?

16, 2012 (note: data before August 7th was lost at this site, so this may not represent peak annual temperatures. These results were consistent with 2010 temperature monitoring by Snohomish County where the peak 7-DADMax of 22.9°C occurred at Russel Rd (SCSWM, 2012).

For sites with a full period of record (June through October), the hottest stream temperatures occurred on August 5, 2012. All of these 2012 dates correspond to periods where the 7-day max air temperatures were greater than the historical 90th percentiles (see meteorology section).

Table 13. Peak daily max and 7-day average daily max (7-DADMax) values from the 2012 data.

Station	Deployment	Peak 7-DADMax °C	Peak Day 7-DADMax	Peak Daily Max °C	Peak Day
Mainstem					
PIL25.5	6/6/12 - 10/9/12	17.62	8/15/12	18.70	8/5/12
PIL21.5	6/6/12 - 10/9/12	20.36	8/15/12	21.22	8/5/12
PIL15.1	8/8/12 - 10/9/12	20.52	8/15/12	21.24	8/16/12
PIL10.4	8/7/12 - 10/9/12	22.05	8/14/12	22.87	8/16/12
PIL8.5	6/6/12 - 10/8/12	21.39	8/14/12	22.56	8/5/12
PIL5.7	8/7/12 - 10/8/12	21.74	8/14/12	22.49	8/17/12
PIL2.0	8/7/12 - 10/8/12	21.64	8/14/12	22.45	8/17/12
Tributaries/Point Sources					
GRA-STP	7/11/12 - 8/21/12; 8/29/12 - 10/9/12	19.57	9/7/12	20.43	8/5/12
LIT-1.8	6/6/12 - 10/9/12	21.35	8/15/12	22.61	8/5/12
DUB-0.0	6/6/12 - 10/8/12	19.85	8/15/12	21.22	8/5/12
CON-0.0	6/6/12 - 8/6/12	21.23	7/9/12	21.99	8/5/12

*Grey shading indicates the annual peak temperature was likely not captured due to data gaps.

Water temperatures were monitored by Ecology in similar way during August 2016. This survey provided greater spatial resolution over a shorter period of time. The results (Table 15) show rapid stream heating from RM 25 to 21 and RM 15 to 11.6, with stable or cooling daily maximum temperatures from RM 21 to 18.7, RM 11.6 to 5.7, RM 3.6 to 2.0. This is generally consistent with previous temperature monitoring (SCSWM, 2012) and estimates of groundwater flow gains (see Groundwater results section).

Table 14. Temperature Results for 8/18/16.

~RM	Temp Min (°C)	Temp Avg (°C)	Temp Max (°C)	Daily Min change rate (°C /mile)	Daily Avg change rate (°C /mile)	Daily Max change rate (°C/mile)
25.5	13.74	n/a	18.41			

Commented [NE(147]: Consider adding more discussion Rapid heating implies less ground water? Your modeling appendix shows ground water in almost all of the reaches, but I can't see the rates What distances do the Vashon till and bedrock layers intersect the river? Does this agree?

Commented [PP(148]: Add a column with the average GW change per mile? Good way to show your point more clearly

Commented [SR(149]: Might change colors a bit, or # of colors, and describe colors to reader in caption (at a minimum)

21.5	15.46	17.98	21	0.43	n/a	0.65
18.7	15.92	18.45	21.14	0.16	0.17	0.05
15.0	16.69	18.93	21.46	0.21	0.13	0.09
11.6	16.81	19.47	22.63	0.04	0.16	0.34
8.5	16.85	19.55	22.56	0.01	0.03	-0.02
5.7	16.91	19.57	22.45	0.02	0.01	-0.04
3.6	17.13	19.68	22.63	0.10	0.05	0.09
2.0	17.16	19.54	22.15	0.02	-0.09	-0.30

The calibrated temperature model suggests solar shortwave and longwave radiation are the dominant physical processes influencing instream temperatures (Figure 17). However hyporheic flow does have a measureable impact on lowering peak afternoon temperatures (see Hyporheic results and discussion section).

Commented [MC(150]: Need to explain what the different shading means

Commented [PP(151]: s f perhaps one decimal place for the data, and 2 for the rates

Commented [NE(152]: Model not introduced yet

Commented [PP(153]: This section is about Field Study Results It's premature to present model results before you've describe your model setup and quality assessment

Commented [SR(154]: I like Figure 17 but when it is compared to the hyporheic results then I wish I was looking at actual temperature changes in the figure below like the graph in Fig 13

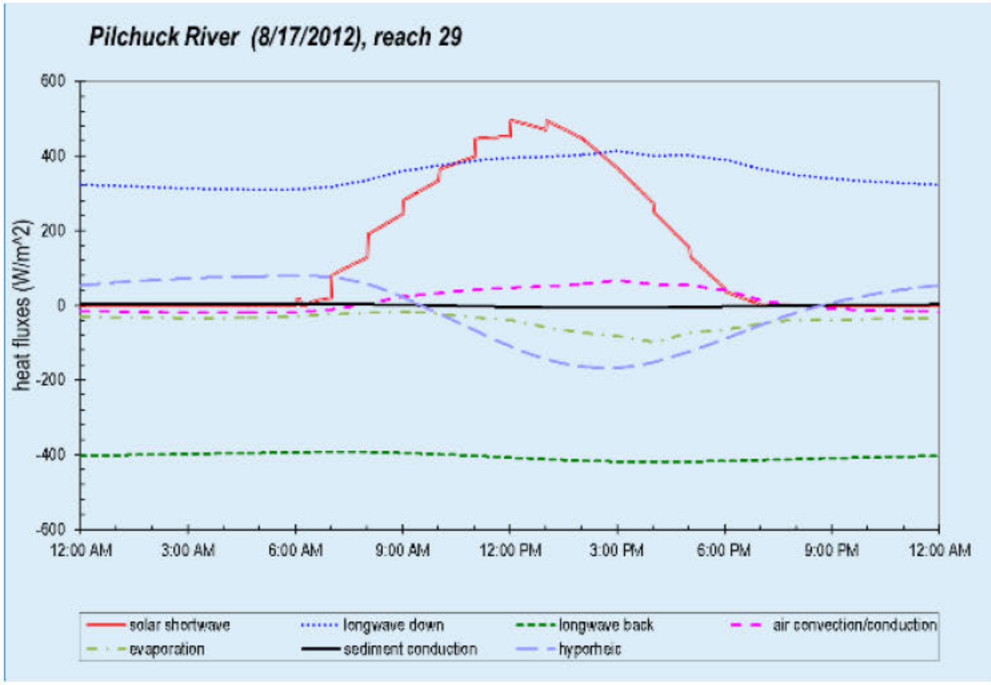

Figure 17. Diel predicted heat fluxes in the Pilchuck River for 8/17/12.

Nutrients

Ecology collected nutrient samples along the mainstem of the Pilchuck River during the two synoptic surveys in 2012, as well as during a synoptic survey on August 17, 2016. The 2016 synoptic survey was conducted to provide additional information regarding nutrient concentrations and water quality below the WWTP and added additional sampling locations at RM 19, 18.7, 17.4, and 11.6.

Commented [NE(155]: You were talking in this section about ground water flow, but this energy balance does not show any ground water effect (of course) The reader may be confused

This seems to belong in a different section

What river mile?

Is this a typical reach?

Figure 18 depicts longitudinal nitrogen concentrations for the three synoptic surveys. The data illustrate several observed patterns:

- Ammonia was typically below the reporting limit.
- Nitrate and total nitrogen decreased from RM 25 to 19 and RM 15 to 10.
- Nitrate and total nitrogen increased steeply from RM 19 to 15 and gradually from RM 10 to 2.

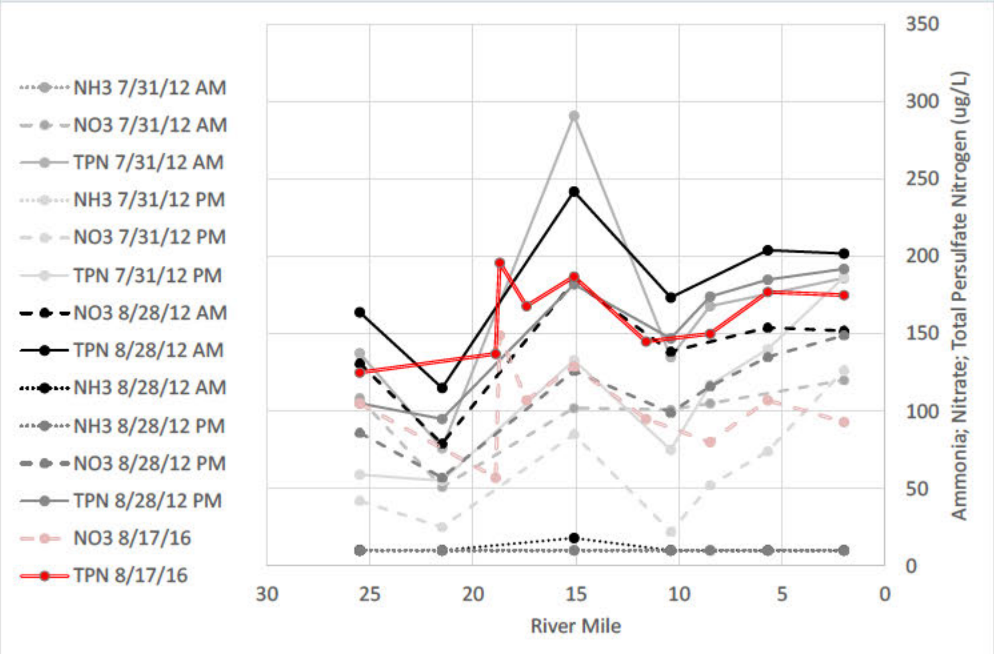

Figure 18. Longitudinal nitrogen concentrations in the Pilchuck River in 2012 and 2016.

Figure 19 depicts longitudinal phosphorus concentrations for the three synoptic surveys. The data illustrate several observed patterns:

Commented [NE(156]: There aren't many points on the figure at RM 19, it looks more like 21.5 has more data

RM 19 has two points very close together, but no time given for these lines. Are you sampling above/below a source or are these mixed AM/PM results?

Commented [NE(157]: The highest value on this plot looks about 290, but I don't see any values that high in Table C-4

Units are wrong in Table C-4

I think that this plot could use some work, it's rather spaghetti-like

Is it worth breaking AM/PM apart? I can't tell anything about AM vs PM

Maybe assign a unique color to each nutrient? Could that simplify the plot? Plot nutrients separately? Not sure how to improve it, or maybe it's not necessary?

- Orthophosphate and total phosphorus decreased from RM 25 to 19 and RM 15 to 2.
- Orthophosphate and total phosphorus increased steeply from RM 19 to 15.

Mass balance analysis and the calibrated model show that the Granite Falls WWTP is the primary source of phosphorus and nitrogen inputs within the Pilchuck TMDL study area.

Commented [PP(158]: Premature to present that here Needs to go down after you present model framework and quality results

Commented [PP(159]: Show location on your graphs (18 and 19)

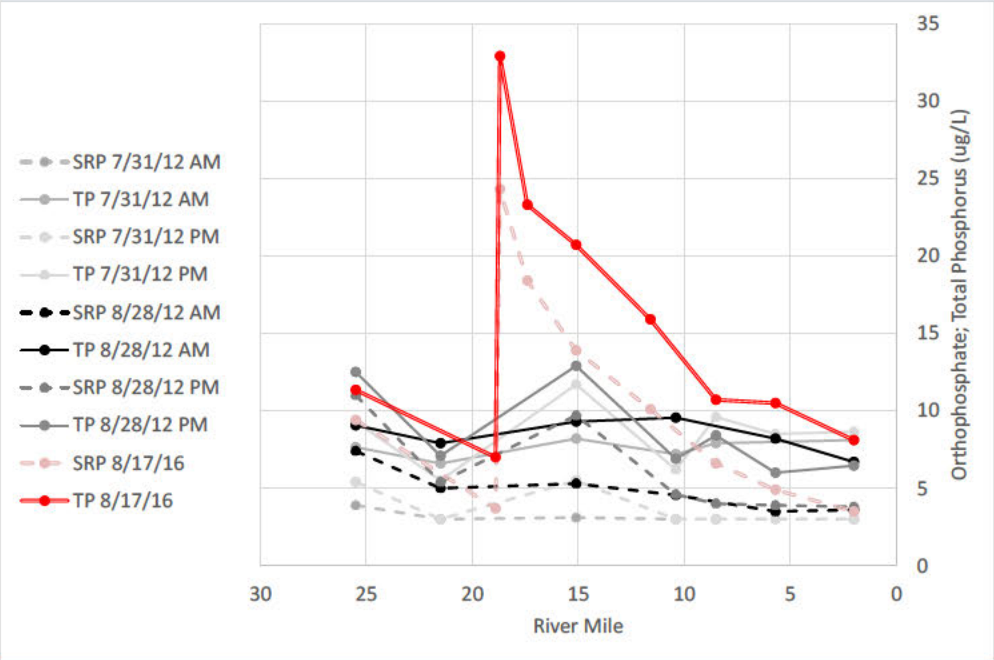

Figure 19. Longitudinal phosphorus concentrations in the Pilchuck River in 2012 and 2016

Periphyton

Biomass

Table 16 contains the periphyton (bottom algae) biomass results from the 2012 field surveys. The average values represent the average of three samples collected at each location, one from the left side of channel, one from the center of the channel, and one from the

Commented [NE(160]: Appendix C uses OP instead of SRP, may want to be consistent

Commented [KH(161]: Has any information been found on whether phosphorus is migrating through groundwater flows?

Commented [PP(162]: What was going on August 17 2016?

RSS looks like we added a site

Commented [PP(163]: Better to add a sentence defining periphyton right side of the channel. The ratio of chlorophyll *a* to ash-free dry weight (AFDW) provides a very general indicator of the relative amount of autotrophic vs heterotrophic productivity, with higher ratios indicating more primary production.

Ecology used the chlorophyll *a* and AFDW content to characterize the range and magnitude of periphyton biomass for use in the model. Site averaged chlorophyll *a* biomass ranged from 3.7 to 23.7 mg/ m^2, with a median of 14 mg/ m^2. Nuisance levels of algae growth are typically an order of magnitude higher 100-200 mg/m^2 (Horner et al., 1983; Welch et al., 1988; Quinn, 1991); however, the QUAL2Kw model indicates the potential effects on dissolved oxygen and pH can be significant in the context of water quality criteria (see *Dissolved Oxygen* discussion).

Commented [MC(164]: What does "primary" equate to, autotrophic or heterotrophic?

Commented [MC(165]: Already defined

Table 15. Periphyton results for the Pilchuck River 2012 study.

Site	RM	Average chlorophyll *a* (mg/m2)	Average AFDW (g/m2)	Ratio of chlorophyll *a* (mg) to AFDW (g)
07-PIL-25.5	25.5	3.7	1.2	3.0
07-PIL-21.5	21.5	23.7	3.4	6.9
07-PIL-15.1	15.1	8.7	2.1	4.1
07-PIL-10.4	10.4	17.2	3.2	5.3
07-PIL-10.4	10.4	20.8	2.8	7.5
07-PIL-8.5	8.5	15.3	2.7	5.6
07-PIL-5.7	5.7	14.0	2.7	5.2
07-PIL-2.0	2	14.0	2.2	6.3

Commented [PP(166]: Curious that the Periphyton drops at 15 1 when the TP spikes at 18 (at least during one month) Where is the WWTP?

Figure 20 depicts the observed vs model predicted periphyton biomass throughout the Pilchuck River on August 28, 2012. The relatively large range in observed values reflects the variability of both the matrix and spatial distribution in the river. Figure 21 illustrates the variability of growth and types of bottom algae within both a single substrate (24b) and throughout different reaches (24 a, c, d).

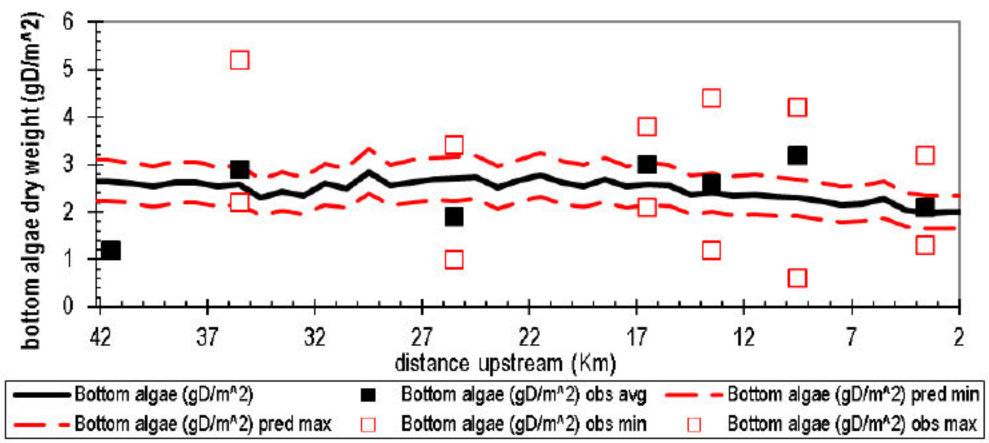

Figure 20. 2012 predicted and observed periphyton biomass levels in the Pilchuck River.

Commented [NE(167]: Point out use of km vs RM to reader

Commented [PP(168]: Up until now it's been all RM, now you introduce Rkm Please be consistent so results can easily be compared
Your squares don't match the results in Table 16

Figure 21. Observed variability in periphyton growth in the Pilchuck River.

Commented [NE(169)]: Text refers to 21 a, b, c, d Add labels

Limitation

Numerous factors can limit or stimulate growth of periphyton in rivers and streams, including: available light and nutrient supply; temperature, grazing and excretion from primary consumers; and scour from changes in velocity or mobilization of substrate (Larned, 2010). When nutrient limitation is evident, one theory is that periphyton growth follows Liebig's Law of the Minimum which states that the nutrient in shortest supply controls growth, typically either nitrogen or phosphorus, although carbon, silica, iron, and other micronutrients can potentially also limit growth (De Baar, 1994).

Cellular and in-stream nutrient concentration ratios are often used as indicators of which nutrient is limiting growth. Nutrient ratios are frequently compared to the Redfield Ratio of 106C : 16N : 1P, a molar ratio derived from an empirical study of average composition of marine organic matter (Redfield, 1934; Redfield 1958). In general if the molar N:P ratio is greater than 16:1, then it is assumed that P is the limiting nutrient and less than that ratio is N-limited. Others have modified the rule to: > 20:1 indicates P-limitation, <10:1 indicates N-limitation, and between 10:1 and 20:1 either nutrient could be limiting (Shanz and Juon, 1983; Borchardt, 1996).

Figure 22 illustrates the relationship of both total and dissolved nitrogen to phosphorus in the Pilchuck River. The results suggest that the river is likely phosphorus limited. The only sections of the river where the ratio is in the ambiguous range (10-20) is immediately below the WWTP (~RM 18.9) where a large influx of phosphorus occurs, and, to a lesser degree, at the upstream boundary of the study area. The nutrient ratio data indicates that the river becomes increasingly phosphorus limited downstream of the WWTP, as phosphorus uptake/loss occurs.

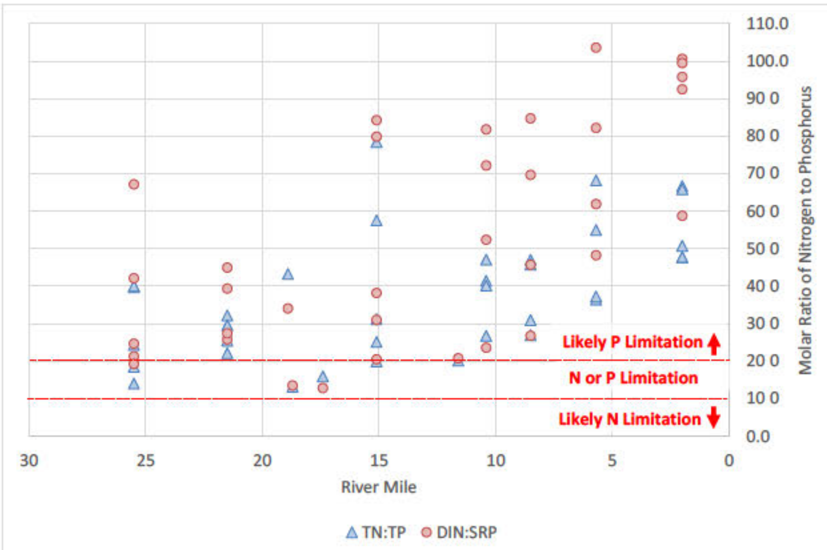

Figure 22. Molar ratio of nitrogen to phosphorus in the Pilchuck River.

TN:TP = *total nitrogen: total phosphorus*
DIN:SRP = dissolved inorganic nitrogen : soluble reactive phosphorus

A sensitivity analysis of periphyton scour shows that removing the scour function for the entire modeling period results in a ~10 to 12% increase in periphyton biomass throughout the river on August 28, 2012 and a corresponding decrease in minimum DO of 0.02 to 0.05 mg/L, depending on the reach.

Figure 23 illustrates the relative effects of the various limiting factors in the model. Over the course of a full day, light has the strongest limiting effect; however, on clear days during the hours of peak solar radiation, phosphorus has the greatest limiting effect. Since the model uses singular nutrient limitation, nitrogen and carbon have no effect. Temperature has a minor limiting effect.

Increased shade and water depth, and decreased phosphorus concentrations, are predicted to be the primary controls for decreasing periphyton growth and productivity in the Pilchuck River.

Commented [PP(170]: Show wwtp

Commented [NE(171]: You didn't discuss periphyton scour yet, introduce topic somehow

Commented [PP(172]: Then how do you calibrate for scour? A priestly mystery? ☺

Commented [MC(173]: This seems important because of the noted changes But need to include some discussion of what the periphyton scour function is and why it was selected (over other parameters) for a sensitivity test

Commented [PP(174]: Temperature has a minor effect on productivity, but what is its effect on saturation? In other words, how much better would DO be just from full implementation of a temperature TMDL? This statement could be confusing if you argue later that improving temperature is good for improving DO

Commented [PP(175]: Shade – through light limitation, or through reduced water temperatures? Or both?

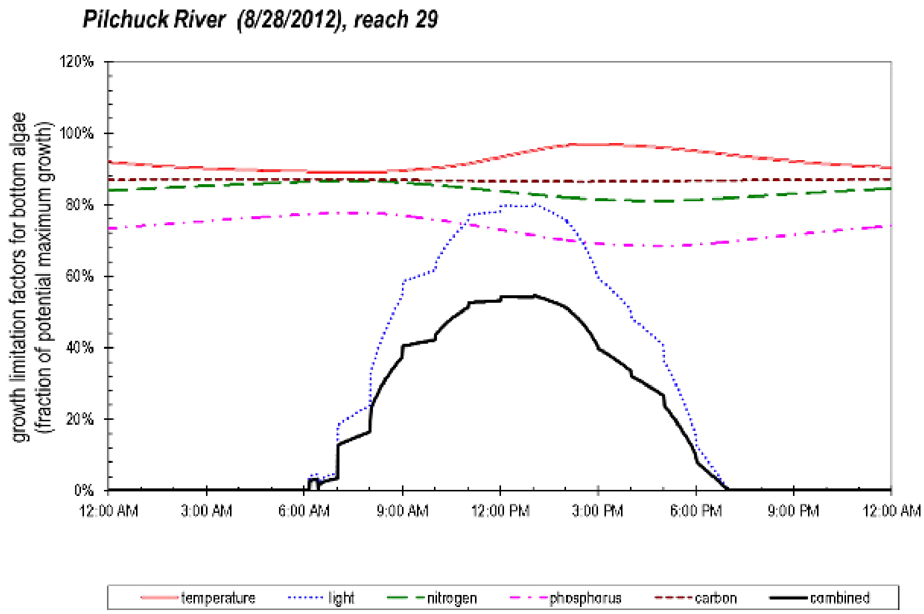

Figure 23. Simulated periphyton growth limitation factors for the Pilchuck River at OK Mill Rd (~RM8.5)

Combined = The cumulative growth limitation effect of all limiting factors (nutrient limitation x light limitation x temperature limitation).

Biochemical oxygen demand (BOD) and carbon

Ecology collected limited 5-day BOD (BOD5) samples from the river during the August 2016 survey. In addition, the Granite Falls WWTP collects three composite BOD5 samples per week from their treated effluent (Table 17).

Commented [NE(176]: Table 17 only shows WWTP results, but here you say they were collected from the river What were the BOD5 results from the river?

For use in the water quality model, BOD5 measurement results were extrapolated to estimates of ultimate CBOD using the formula:

$$\mathrm{CBODU} = \frac{\mathrm{CBOD5}}{1 - e^{-k_1 5}}$$

where CBODU = the ultimate dissolved carbonaceous BOD [mgO_2/L], CBOD5 = the 5-day dissolved carbonaceous BOD [mgO_2/L], and k_1 = the CBOD decomposition rate in the bottle [/d].

The reported Granite Falls WWTP BOD5 result for August 29, 2012 was 15.1 mg/L, using this equation the CBODu estimate equals 45.8 mg/L. This estimate is consistent with an independent rough estimate of the CBODu of 49 mg/L derived using the DOC result from August 28, 2012 of 15.9 mg/L and the model ratio of oxygen consumed during carbon oxidation of 3.08 g0^2/gC. The value of 3.08 is the average of the stoichiometric ratios for the amount of oxygen consumed during plant respiration if ammonia or nitrate is the substrate, 2.69 and 3.47 respectively.

Table 16. Statistics for WWTP BOD5 sample results between 6/6/12 and 10/11/12

Commented [PP(177]: The UBOD value used in the model is inextricably linked to the k value (CBOD decay rate) in the model What did you use for modeling?
Also, it might be interesting to compare you UBOD rate to other studies UBOD rates tend to be a function of the type of waste and type of treatment Lagoons can produce low UBOD with low k rates (lots of refractory carbon) The other end of the extreme is food processing waste that can have a high UBOD with a high k rate (lots of reactive short-molecule carbs) Rates for similar kinds of treatment plants from other studies would be a reasonable comparison

	BOD5 (mg/L)	Ultimate CBOD estimate
Count =	38	n/a
Minimum =	2.3	7.0
Mean =	7.2	21.7
Median =	6.6	20.0
Maximum =	15.7	47.6
Standard Deviation =	3.3	n/a
Coefficient of Variance =	0.5	n/a

During the 2012 synoptic surveys, total and dissolved organic carbon levels were typically fairly low in the river, with dissolved organic carbon often below the reporting limit of 1 mg/L (Figure 24). The calibrated model suggests there is a significant source of organic carbon and cBOD that was not captured by the study data collection (see Appendix E *Model Documentation* for further discussion).

Commented [PP(178]: I think this should go later after you discuss calibration Maybe say "this will be discussed further under modeling "

Organic carbon and cBOD was not measured in groundwater or minor tributaries for the study, so this value is unknown. The additional source of carbon fueling heterotrophic productivity in the sediments is unknown but could reasonably be contributed by some combination of groundwater (particularly from off stream wetlands), buried particulate organic matter from storm events during the winter/spring, or settling organic matter during the model period.

Commented [PP(179]: I think the discussion of unknown sources belongs later in discussing model results
Can you separate SOD from unknown sources like tributaries and nonpoint soucres? Is the "heterotrophic productivity in sediments" you describe the same as old-fashioned SOD?

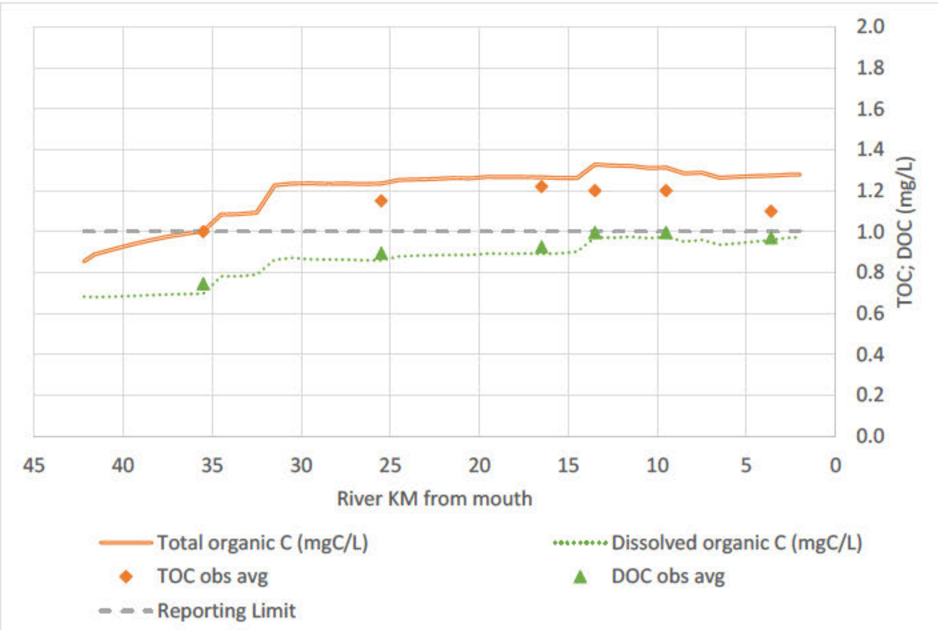

Figure 24. Model simulated vs. observed total and dissolved organic carbon in the Pilchuck River on 8/28/12.

Commented [MC(180]: Would be better to have solid line legends as Modeled TOC and Modeled DOC

Commented [PP(181]: These seems premature to show here when you haven't presented model calibration yet But I know there's no perfect way to order things in these reports

Stream metabolism (RMA)

Ecology's River Metabolism Analyzer (RMA) (Pelletier, 2013) tool was used to provide estimates of gross primary productivity (GPP), ecosystem respiration (ER), and reaeration. This provides alternate estimates of these processes to compare to the outputs from the QUAL2Kw model.

RMA estimates of reaeration averaged 12.8 gO_2/m^2/day and ranged from 9.5 to 24.1 gO_2/m^2/day, depending on the method used (Delta, nighttime regression, or inverse modeling), survey date, and location (Table 18). Ultimately, the average of the Delta and nighttime regressions were compared to model predicted reaeration during calibration.

Table 17. Reaeration estimates for the Pilchuck River based on 2012 diel data.

RM	Date	Delta Method	Nighttime Regression	Inverse Modeling	Avg DO Reaeration (no inverse modeling)
		DO reaeration (centroid)	DO reaeration	DO reaeration	
5.7	7/31/2012	16.6	13.22	14.88	14.9
8.5	7/31/2012	18.4	10.02	24.05	14.2
5.7	8/28/2012	14.4	9.82	19.34	12.1
8.5	8/28/2012	14.8	9.5	10.66	12.2
10.4	8/28/2012	12.7	8.25	14.05	10.5
	Average =	15.4	10.2	16.6	**12.8**
	Median =	14.8	9.8	14.9	**12.2**

Hobson et al. (2014) suggests that the sediment oxygen demand (SOD) can be estimated by subtracting the GPP from ER, assuming that in net heterotrophic systems (ER is greater than GPP) the additional respiration comes from the sediment or hyporheic zone. RMA estimates of SOD ranged from 0.9 to 2.6 gO_2/m^2, with an average of 1.7 (Table 19). All estimates of GPP and ER indicated the Pilchuck River was net heterotrophic, with the ratio of GPP:ER consistently between 0.6 and 0.8.

Commented [PP(182]: See my earlier comment on this topic Clarify the relationship between the discussions

Table 18. Gross primary productivity, ecosystem respiration, and sediment oxygen demand estimates for the Pilchuck River based on 2012 diel data.

RM	Date	Delta Method			Inverse Modeling			Estimated SOD
		Avg GPP (cent)	Avg Resp (cent)	GPP:ER	Avg GPP	Avg Resp	GPP:ER	
5.7	7/31/2012	2.7	4.5	0.60	2.09	3.63	0.58	1.7
8.5	7/31/2012	4.3	5.3	0.81	4.89	6.37	0.77	1.2
5.7	8/28/2012	3.4	5.6	0.61	4.00	7.01	0.57	2.6
8.5	8/28/2012	2.6	3.6	0.72	1.76	2.61	0.67	0.9
10.4	8/28/2012	4.9	6.3	0.78	4.88	7.21	0.68	1.9
	Average =	3.6	5.1	0.7	3.5	5.4	0.7	**1.7**
	Median =	3.4	5.3	0.7	4.0	6.4	0.7	**1.7**

Dissolved oxygen and pH

Ecology collected continuous DO and pH data during two surveys in July and August of 2012, and one survey in August 2016. Observed DO minima consistently fell below water quality criterion during all three surveys (Table 20). In general DO was lowest between RM 12 and 2, in the downstream reaches; however, values below the criterion were observed at the upstream stations as well.

Observed pH fell within the criteria during all surveys; however, PIL 25.5 reached the upper limit of 8.5 on one day in July 2012. pH values were typically highest in the upstream reaches and lowest in the downstream reaches.

Table 19. Observed DO and pH minimums and maximums during the 2012 and 2016 surveys.

Location_ID	July 30 - Aug 2, 2012		August 27 - 30, 2012		August 16 - 19, 2016		DO criteria
	DO Max	DO Min	DO Max	DO Min	DO Max	DO Min	
07-PIL-25.5	11.41	9.55	11.07	9.58	10.68	9.04	> 9.5 mg/L
07-PIL-21.5					10.59	8.7	> 9.5 mg/L
07-PIL-18.7					10.14	8.39	> 9.5 mg/L
07-PIL-15.1					9.65	7.88	> 9.5 mg/L
07-PIL-11.6					10.32	8.13	> 9.5 mg/L
07-PIL-10.4			10.33	8.51			> 9.5 mg/L
07-PIL-8.5	10.6	8.6	10.33	8.49			> 9.5 mg/L
07-PIL-8.2					9.98	8.37	> 9.5 mg/L
07-PIL-5.7	10.12	8.59	10.39	8.71	10.27	8.11	> 9.5 mg/L
07-PIL-3.6					10.03	7.98	> 9.5 mg/L
07-PIL-2.0					10.02	8.15	> 9.5 mg/L
07-LIT-1.8			9.39	8.47			> 9.5 mg/L
Location_ID	**July 30 - Aug 2, 2012**		**August 27 - 30, 2012**		**August 16 - 19, 2016**		**pH criteria**
	pH Max	**pH Min**	**pH Max**	**pH Min**	**pH Max**	**pH Min**	
07-PIL-25.5	8.5	7.5	8.14	7.53	7.86	7.36	6.5 to 8.5
07-PIL-21.5					7.91	6.98	6.5 to 8.5
07-PIL-18.7					7.89	7.35	6.5 to 8.5
07-PIL-15.1					7.39	7.04	6.5 to 8.5
07-PIL-11.6					7.78	7.07	6.5 to 8.5
07-PIL-10.4			8.06	7.45			6.5 to 8.5
07-PIL-8.5			7.72	7.26			6.5 to 8.5
07-PIL-8.2					7.79	7.36	6.5 to 8.5
07-PIL-5.7	7.76	7.33	7.78	7.42	7.85	7.26	6.5 to 8.5
07-PIL-3.6					7.72	7.18	6.5 to 8.5
07-PIL-2.0					7.59	7.11	6.5 to 8.5

07-LIT-1.8			7.68	7.42			6.5 to 8.5
07-CON-0.0	7.64	7.5					6.5 to 8.5

Highlighted cells denote values below the minimum DO criterion.

The results of simulated diel DO fluxes from the QUAL2Kw model (Figure 25) indicate that:

- The primary sources of increased DO are periphyton photosynthesis (daylight) and reaeration (nighttime).
- Periphyton respiration and hyporheic sediment oxygen demand (SOD) (driven by cBOD inputs to hyporheic zone) are the primary factors decreasing DO minimums (night/early morning).
- Phytoplankton photosynthesis/respiration, cBOD in the water column, and nitrification are all predicted to have a negligible effect on DO levels.

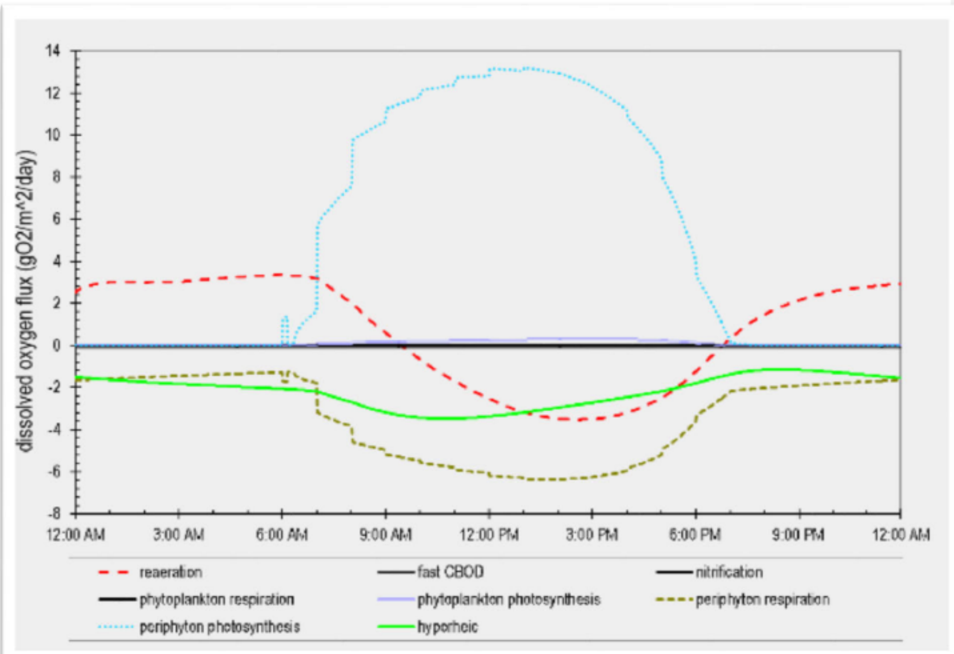

Figure 25. Predicted influences on diel dissolved oxygen fluxes for Pilchuck at OK Mill Rd on 8/17/12.

Temperature TMDL Analysis and Allocations

System potential conditions

The calibrated QUAL2Kw model was used to estimate the temperatures that would be expected to occur under system potential conditions. System potential conditions are conditions that do not include human modifications to riparian vegetation. The system potential condition serves as an estimate of natural conditions, as defined by the state water quality standards.

To estimate system potential DO conditions, the QUAL2Kw model was modified in the following ways:

- Point source effluent discharges were removed from the simulation.
- Shade inputs were changed to reflect system potential riparian vegetation.
- The upstream end of the model domain and tributary boundary conditions were modified to decrease temperatures to meet water quality criteria.
- 2012 air temperatures were reduced by 2°C to reflect potential microclimate effects from system potential riparian vegetation. Dew point temperatures were increased by 1.0°C, except for at times when that would result in a relative humidity of 100% or greater.

Complete documentation of the model inputs and values used can be found in Appendix E under the heading “System Potential Conditions Model Inputs.”

It was not possible to accurately include all human modifications to the river system in the model. Some known or suspected human modifications were omitted, including changes to groundwater/hyporheic flow and channel geometry. Analysis of these factors is outside the scope of this study and represent very complex environmental processes that would be difficult to estimate with a moderate level of certainty.

System potential conditions were simulated continuously for the time period from June 7 to October 9 using 2012 meteorological conditions. Figures 28-29 present the simulation results for system potential conditions in the Pilchuck River.

Compliance with standards

During the 2012 study year, the model predicted that the entire river would fail to meet the 7-DADMax criterion for Core Summer Salmonid Habitat (16°C) during the month of August. Much of the river also failed to meet the 16°C criterion during the months of July and September, and the lower river failed to meet the supplemental spawning criterion (13°C) in early to mid-June. The river did meet the 16°C criterion in late June and from late September to early August (Figure 27). These predictions were confirmed by the observed data (see Temperature results section).

The system potential model was run with upstream flows from a 7Q10 critical low-flow year (2004) to compare 7-DADMax temperature to TMDL scenarios (Figure 28). The peak 7-DADMax temperature was reduced by 2°C for the most critical day (8/14/12). However, much of the river still failed to meet the 16°C criterion during the months of July and August.

Because 2004 flows were more average in June and September, an additional system potential model run was conducted with flows from 2009 (near 7Q10 flows for these specific months). Figure 29 depicts this run and shows that although a small portion of the lower river would fail to meet the 13°C criterion in June, the river would meet the 16°C criterion from September to early October. The larger improvement in September compared to August is mostly due to the increased influence of riparian shade later in the year as the angle of the sun becomes lower.

In the case of both the 2004 and 2009 system potential model years, 7-DADMax values in the river would be reduced below the threshold for acute lethality in moderately acclimated adult and juvenile salmon of 22°C identified by the water quality standards (WAC 173-201A-200(1)(c)(vii)(A)).

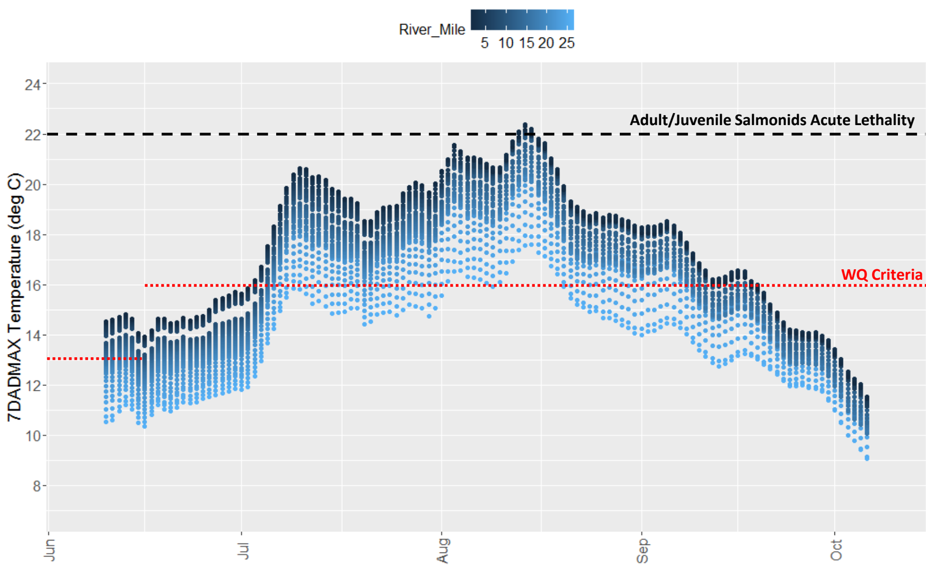

Figure 26. Existing 2012 model predicted 7-DADMax temperature compared to WQ criteria.

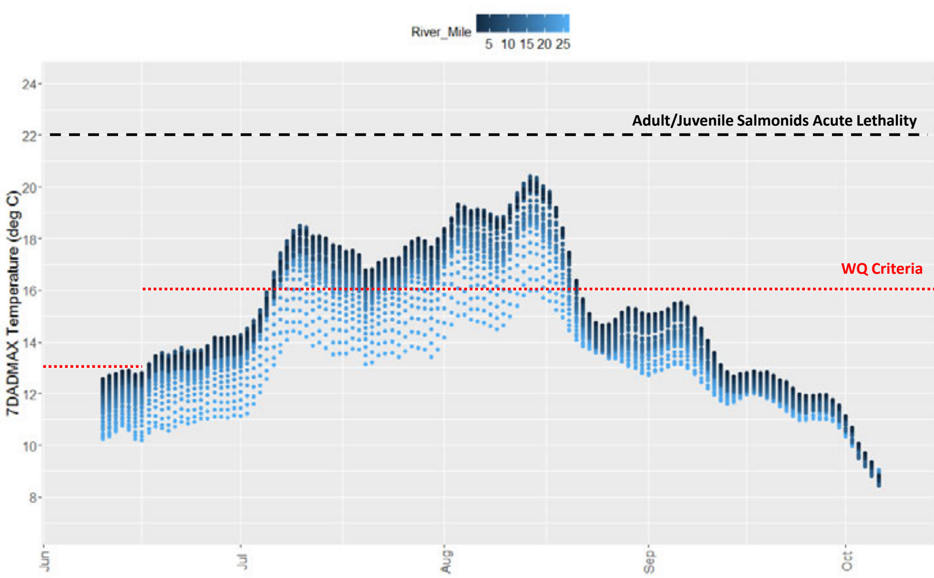

Figure 27. System potential model predicted 7-DADMax temperature with 2004 flows.

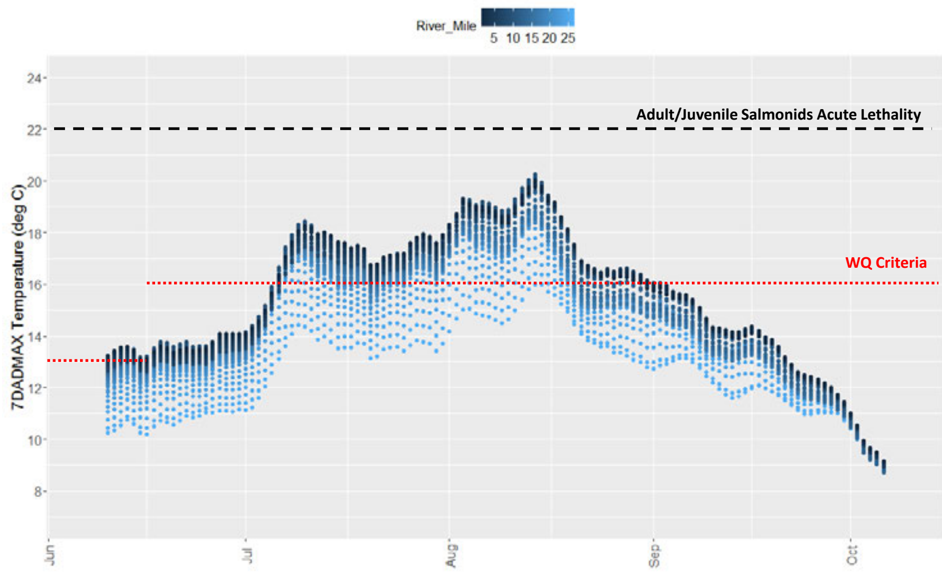

Figure 28. System potential model predicted 7-DADMax temperature with 2009 flows.

Loading capacity

EPA's current regulation defines loading capacity as "the greatest amount of loading that a water can receive without violating water quality standards" (40 CFR § 130.2(f)). The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring water into compliance with standards. Loading capacities for the Pilchuck River are the solar radiation heat loads that either allow stream temperatures to stay below the numeric criteria, or else not exceed the natural condition by more than 0.3°C.

The calibrated QUAL2Kw model and the Shade model were used to estimate the assimilative load capacity for temperature in the Pilchuck River, which is the basis for the load and wasteload allocations assigned in this TMDL.

This TMDL uses the modeled system-potential temperature as an approximation of the natural temperature *during critical high air temperatures and low-flow conditions*. TMDL load allocations are supposed to be set for the critical condition in order to be protective of the stream during the rest of the year. The modeled system-potential condition uses best estimates of potential mature riparian vegetation and riparian microclimate. The TMDL design condition is the system-potential condition with "minimized human disturbance".

The calibrated QUAL2Kw model was used to determine the loading capacity in the Pilchuck River. Loading capacity was determined based on prediction of water temperatures under low-flow (7Q10) and extreme climate (95^{th} percentile) conditions combined with a range of effective shade conditions.

Ecology evaluated a series of scenarios that are expected to reduce the Pilchuck River water temperature including:

- **System potential shade (SPS)**. This scenario would be provided by 180-ft wide buffers of system-potential mature (100-year) riparian vegetation along the Pilchuck River.
- **Microclimate improvements (MC).** Increases in vegetation height, density, and riparian zone width are expected to result in localized decreases in air temperature. To evaluate the effect of this potential change in microclimate on water temperature, all hourly air temperatures along the Pilchuck River mainstem were reduced by 2ºC based on the summary of literature presented by Bartholow (2000). Because much of the Pilchuck River is wide compared to the area of riparian overhang, this may or may not be a valid expected improvement.
- **Reduced headwater and tributary temperatures (BC).** A scenario was evaluated with the assumption that the inflowing headwaters and tributaries, or boundary conditions (BC), did not exceed the water quality numeric criteria of 16°C.
- **Some baseflow restored (WR).** Restored flow based on typical Snohomish water treatment plant withdrawal and 100% of surface water withdrawal rights. While 100% of surface water rights are likely not being used, this provides some compensation for the fact that groundwater withdrawal/impacts were not evaluated. This scenario was included for informative purposes and was not part of the scenario used to develop allocations.

Figure 30 depicts the longitudinal daily maximum temperature results of these modeling scenarios for critical June, August, and September conditions. While daily max values are not equal to 7-DADMax values, they are highly correlated. The results show the river would meet the applicable 1-day max thresholds identified in the WQ standards of 23°C (acute adult/juvenile lethality) during August critical conditions and 17.5°C (fish embryo lethality) during September Chinook spawning.

This TMDL is designed to protect against temperature impairments during the entire critical season of June through September. While the most critical conditions occur at lower flows during the period of late July to mid-August, temperature WLAs must be designed to be protective during other conditions, including summer storms.

The heat loading capacity for this TMDL is dynamic. The daily load capacity is determined by the allowable heat load over the water quality criteria using the following equation:

$$\text{Daily Load Capacity (therms/day)} = 0.3°\text{C (allowable } \Delta) * \text{River Flow} * 97.1$$

Where 97.1 equals a conversion factor to therms/day (therm / (cfs * degC))

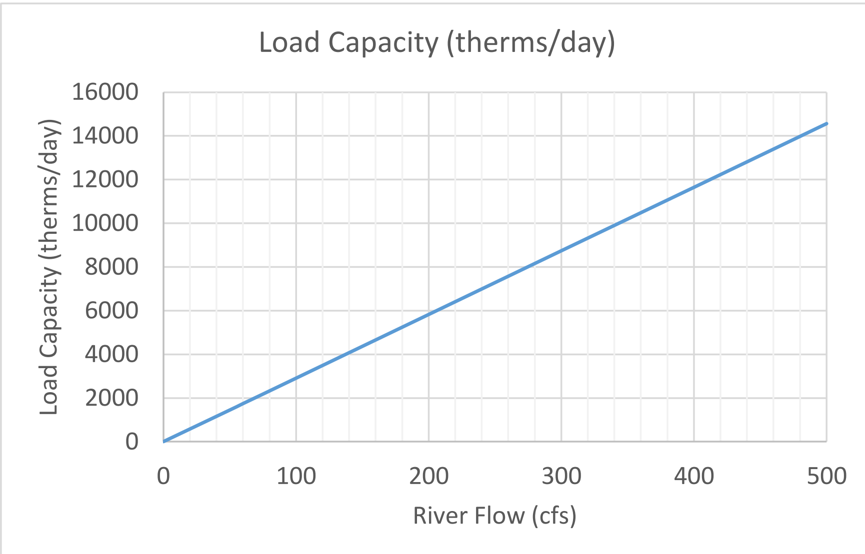

Figure 29. Heat load capacity for the Pilchuck River as a function of river flow.

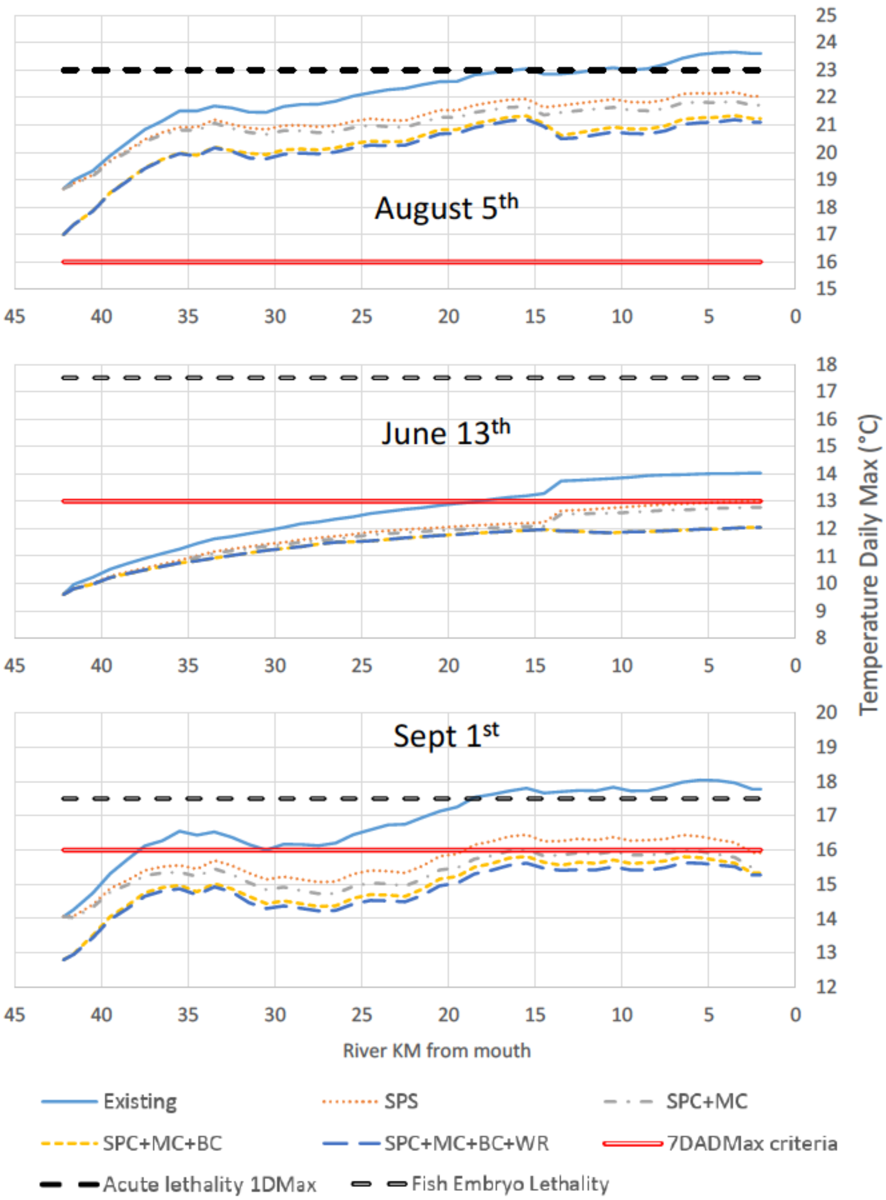

Figure 30. Daily max water temperatures for existing (2012) conditions and improvement scenarios.

Wasteload allocations

Table 21 lists the point source discharges in the *Pilchuck River Temperature and DO TMDL* study area that have NPDES permits. Appendix H provides a more detailed accounting of individual permittees within the watershed, including current activity level and potential to discharge to surface water.

Commented [SR(183]: We need to update the Appendix

Table 20. Dischargers in the watershed covered by NPDES Permits.

Permit Type	Receiving Waterbody	Permittee Name	Permit #
Municipal NPDES Individual permit IP	Pilchuck River	GRANITE FALLS WWTP	WA0021130
Sand and Gravel General permit	Trib of Pilchuck	Pilchuck Sand & Gravel Inc	WAG503379
	Groundwater	Riverside Sand & Gravel	WAG 503086
	Facility inactive	Granite Falls Quarry L Matheson	WAG503085
	Groundwater	Lake Industries Menzel Lake Gravel	WAG503312
	Unknown	Jaxico Real Estate Investment Group LLC	WAG994258
	Ditch to Little Pilchuck	Thomco Aggregate LLC	WAG503027
	Pond	Premier Pacific Properties, (Island Construction Site & Utilities)	WAG503327
	EF Little Pilchuck	Concrete Norwest Getchell Pit	WAG503166
	Pond next to Pilchuck River	D&D Excavating (Marysville Const & Paving Co)	WAG503046

Table 21. Stormwater NPDES permits in the Pilchuck TMDL as of spring 2017.

Stormwater Permit Type	Receiving Waterbody	Permittee Name	Permit #
Construction general permit	Pilchuck Watershed	Numerous; transient	
Industrial general permit	Little Pilchuck	Central Steel	WAR012091
	Little Pilchuck	Northwest Auto Recyclers	WAR303981
	Pilchuck River	UPF Washington LLC (NEPA Pallet & Container)	WAR000752
Municipal general permit	Pilchuck Watershed	Snohomish County- Phase 1	WAR044502
	Pilchuck Watershed	City of Granite Falls- Phase 2	WAR045517
	Pilchuck Watershed	City of Lake Stevens- Phase 2	WAR0021130
	Pilchuck Watershed	City of Snohomish- Phase 2	
Transportation general permit	Pilchuck Watershed	WSDOT	WAR043000

Wasteload allocation for Granite Falls Wastewater Treatment Plant

Discharges to state waters are regulated through permits as part of the NPDES program. A facility with an NPDES permit is considered a "point source" of pollution. The Washington State water quality standards (WAC 173-201A) restrict the amount of warming that point sources can cause when river or stream temperatures are cooler than the numeric criteria:

> *Incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/(T+7) as measured at the edge of a mixing zone boundary (where "T" represents the background temperature as measured at a point or points unaffected by the*

discharge and representative of the highest ambient water temperature in the vicinity of the discharge).

At times and locations where the assigned numeric criteria cannot be attained even under estimated natural conditions, the state standards hold human warming to a cumulative allowance for additional warming of 0.3°C above the natural conditions estimated for those locations and times.

Maximum effluent temperatures should also be no greater than 33°C to avoid creating areas in the mixing zone that would cause instantaneous lethality to fish and other aquatic life.

The load allocations for the nonpoint sources are considered to be sufficient to attain the water quality standards by resulting in water temperatures that are equivalent to natural conditions. Therefore, the standards allow an increase over natural conditions for the point sources for establishing the wasteload allocations. However, point sources must still be regulated to meet the incremental warming restrictions established in the standards to protect cool water periods.

Maximum effluent discharge temperature was calculated for the NPDES permit holders in the Pilchuck River basin. Effluent temperatures that would increase the river temperature by 0.3°C were calculated at the edge of the mixing zone. Ecology used a mass balance equation and provisions in Washington State water quality standard (WQS) which allow mixing zones of up to 25% by volume of the streamflow. Tables 21 and 22 show the wasteload allocations for these dischargers at critical river flows. Appendix F contains extended data tables with effluent temperature limits and wasteload allocations for varying effluent and river flows.

Commented [PP(184]: I'm confused Are you giving every discharger 0 3? If so, that contradicts the standards which say "human actions considered cumulatively" cannot increase temperatures by 0 3 Even giving all the dischargers together 0 3 does not take NPS into account

Commented [nlm185R184]: Clarified The important difference is " at the edge of the mixing zone"

In Washington State, the months likely to exceed the water temperature criteria are June through September, with most occurrences in July and August. June and September generally are cooler but often have a lower aquatic life temperature criterion to be protective of spawning salmonids. Because streamflow is lower during July and August when stream temperature is at its highest, a wasteload allocation generated with the flows that correspond to that period is protective of the aquatic life standard and is appropriate.

The WLAs for this TMDL are dynamic and set as a percentage of the dynamic loading capacity, as determined by the flow in the river (Figure ?).

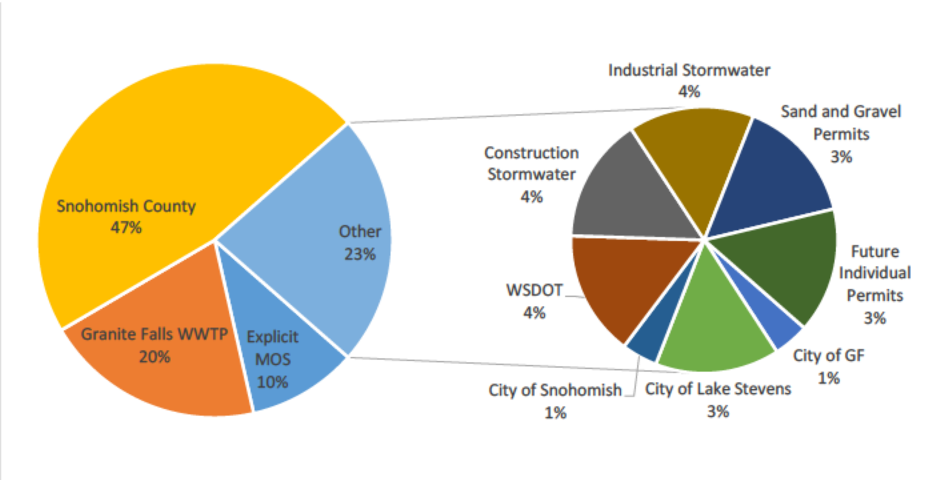

Figure 31. Allocation of heat load capacity.

Dynamic wasteload calculations are determined for the river by the following 5 step process:

1. Determine the dynamic loading capacity as defined by Equation 1 (see *Loading Capacity*).
2. Calculate the allowable dynamic dilution factor as defined by Equation 2.
3. Calculate the allowable effluent temperature (TNPDES) for the Granite Falls WWTP using either equation 2 or 3 (depending on date).
4. Determine the WLA (in therms/day) for the Granite Falls WWTP using TNPDES (Step 3), the effluent flow, and equation 4. Alternately, determine the WLA by multiplying the loading capacity (step 1) by a 0.2.
5. Determine the remaining WLA for other NPDES permits by multiplying the loading capacity (step 1) by the percentages in Figure 35.

The Granite Falls WWTP NPDES discharge is assigned a conditional maximum temperature wasteload allocation, based on maximum allowable effluent temperatures (T_{NPDES}), Pilchuck river flow, and effluent flow as follows:

The dynamic dilution factor is recalculated daily as:

Equation 2: Equation to calculate dynamic dilution factor.

Commented [nlm186]: Joan – I'm struggling figuring out the best way to caption the equations Can you help with that? Thanks!

$$Dynamic\ dilution\ factor = (0.25 * Downstream\ flow * 0.85\,) + (Effluent\ flow)\ /\ Effluent\ flow$$

Where:

Downstream flow = the daily average flow in cfs measured at the USGS gage 12155300 Pilchuck River near Snohomish, WA.

Effluent flow = the current daily effluent flow in cfs from Granite Falls WWTP.

0.85 = Conservative ratio of flow at Granite Falls WWTP outfall compared to flow at USGS gage 12155300; Pilchuck River near Snohomish, WA

The maximum allowable effluent temperature (T_{NPDES}) is calculated using the dynamic dilution factor and seasonal temperature criteria:

From June 16 to February 14:

$$TNPDES = [16°C - 0.3°C] + [dynamic\ dilution\ factor] * 0.3°C$$

From February 15 to June 15:

$$TNPDES = [13°C - 0.3°C] + [dynamic\ dilution\ factor] * 0.3°C$$

The dynamic wasteload allocation (in therms/day) for the Granite Falls WWTP is determined by the temperature above the criterion and effluent flow using the following equation:

$$Daily\ WLA = \{TNPDES - Tcriterion\} * effluent\ flow * 97.1$$

Where:

97.1 equals a conversion factor to therms/day (therm / (cfs * degC))

$T_{criterion}$ = the applicable water quality criterion in °C

1 therm = 100,000 BTU = 105,506 kilojoules = 25,200 kilocalories = 29,307 Watt/hr

For example, if T_{NPDES} = 21.5, $T_{criterion}$ = 16, and effluent flow = 1.2 cfs, then the:

Granite Falls WWTP Daily WLA = (21.5 – 16) * 0.8 * 97.1 = 427 therms/day

During baseflow 7Q10 conditions very little discharge (5% of 7Q10) from stormwater or other NPDES permittees is expected or allowed. Table 22 depicts an example of WLA Following the 5 step process identified above for 7Q10 low-flow conditions.

Table 22. Example of wasteload allocations at 7Q10 Flow conditions when criterion is 16°C.

Permittee	River Temp Allowance (°C)	Discharge (cfs)	Load Capacity (therms/day)		Percent of load capacity
	0.27	41.8	1,096	Available	90%
	0.03		122	MOS	10%
			1,218	Total	
	TNPDES (°C)	**Temp above (°C)**	**Effluent Discharge (cfs)**	**WLA (therms/ day)**	
Granite Falls WWTP	19.4	3.4	0.78	243	20%
Other NPDES permits	20.2	4.2	2.09	853	70%

During a summer storm, the river flow increases due to runoff and the loading capacity changes (increases). A storm from August 2012, where the river flow increased from baseflow to ~63 cfs, was evaluated as an example (Table 2). The calculation assumes that 30% of the flow originates from a permitted source (e.g., municipal stormwater infrastructure, state highways). Other NPDES discharges would be expected to discharge stormwater/effluent at 16.7°C to meet the WLA.

Table 23. Example of wasteload allocations during August storm conditions when criterion is 16°C.

Permittee	River Temp Allowance (°C)	Discharge (cfs)	Load Capacity (therms/day)		Percent of load capacity
	0.27	62.5	1,639	Available	
	0.03		182	MOS	10%
			1,821	Total	
	TNPDES (°C)	**Temp above (°C)**	**Effluent Discharge (cfs)**	**WLA (therms/ day)**	
Granite Falls WWTP	20.0	4.0	1*	365	20%
Other NPDES permits	16.7	0.7	18.75	1,273	70%

* For conservative measure, set even higher then max future effluent flow 0.78 cfs, assuming some infiltration and inflow issues during storms.

Given the more stringent criterion during early June (13°C), a June 2012 storm, where the river flow increased to ~400 cfs, was also evaluated (Table 3). The calculation again assumes that 30% of the flow originates from a permitted source (e.g., municipal stormwater infrastructure, state highways). Other NPDES discharges would be expected to discharge stormwater/effluent at 13.7°C to meet the WLA.

Table 24. Example of wasteload allocations during early June storm conditions when criterion is 13°C.

Permittee	River Temp Allowance (°C)	Discharge (cfs)	Load Capacity (therms/day)		Percent of load capacity
	0.27	400	10,487	Available	
	0.03		1,165	MOS	10%
			11,652	Total	
	TNPDES (°C)	**Temp above (°C)**	**Effluent Discharge (cfs)**	**WLA (therms/ day)**	
Granite Falls WWTP	28.5	15.5	1.64	2,338	20%
Other NPDES permits	13.7	0.7	120	8,148	70%

Figure 33 illustrates the range of effluent temperatures and wasteload allocations expected under current and future summer low-flow conditions. In general, effluent temperatures would need to be less than 22.8°C at current effluent flows and less than 19.4°C if flows are doubled in the future.

Commented [LJ(187]: Figure, not table?

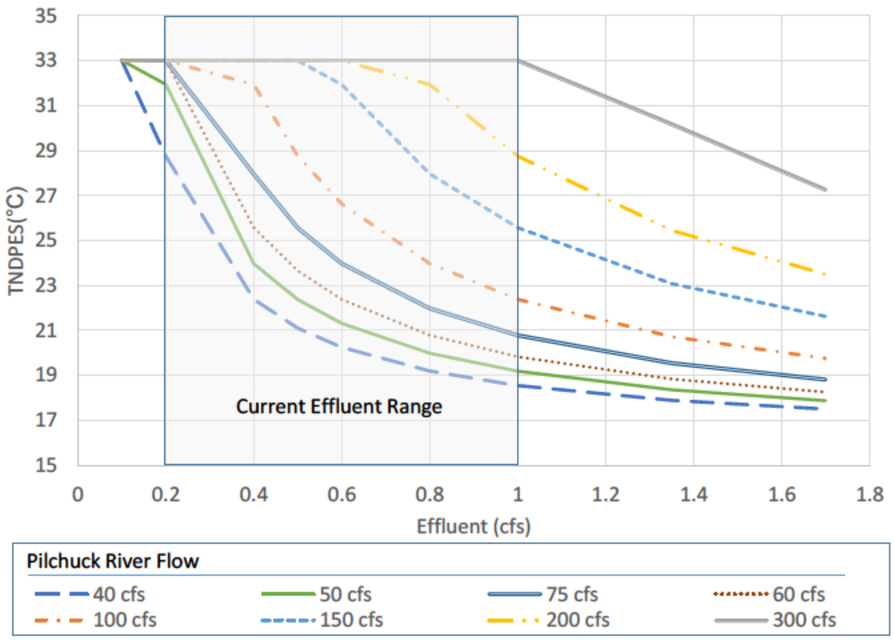

Figure 32.

Figure 34 illustrates the range of effluent temperatures and wasteload allocations expected under current and future spring supplemental spawning low-flow conditions. In general, effluent temperatures would need to be less than 17.1°C at current effluent flows and less than 15.0°C if flows are doubled in the future.

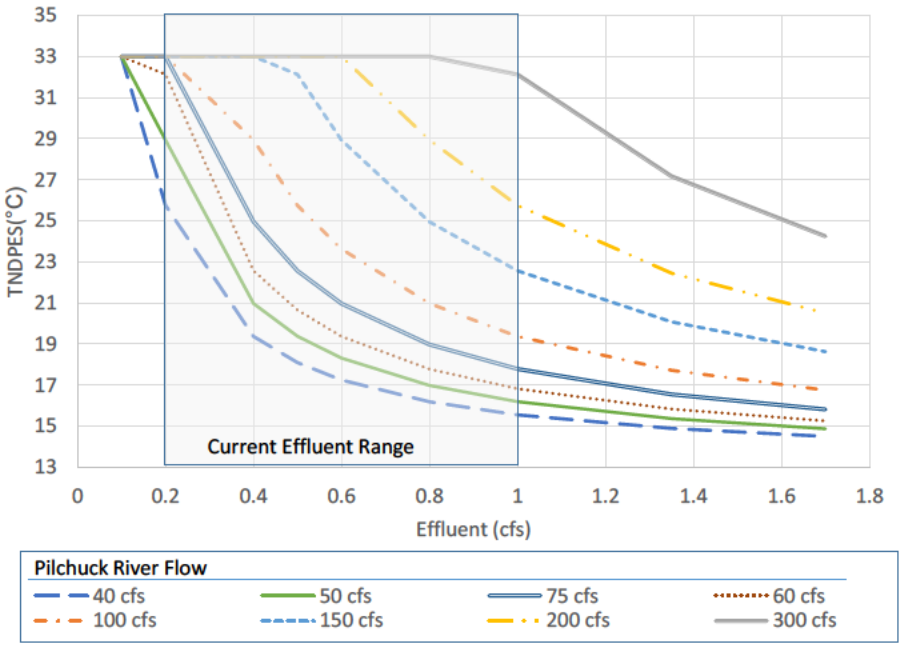

Figure 33.

Stormwater and general permit wasteload allocations

Wasteload allocations are necessary for permitted stormwater discharges if they are a source of pollutant loading to the stream when receiving water temperatures are impaired. The Pilchuck River watershed has permitted stormwater sources discharging into its mainstem and tributaries.

Temprature monitoring during June 2012 storms shows that runoff in the Little Pilchuck watershed does not appear to increase water temperatures and is instead correlated with cooler temperatures in the stream (Figure 35). Relative to other basins in the Pilchuck watershed, the Little Pilchuck, which includes much of Lake Stevens, has a larger drainage area and more development.

Commented [KH(188]: Do we have monitoring data on the MS4 outfalls coming into the tribs or mainstem? I would expect folks to ask what percentage of the WLA is coming from stormwater/MS4 and what actions are needed on the stormwater side to improve temperature and DO for the Pilchuck River watershed

Commented [SR(189]: Move this discussion up? Might expand on the text a little (last sentence) and explain why that is significant I am wondering if some excerpt from or reference to the Snoqualmie temp TMDL discussion might be useful here This is a bit counterintuitive at first but I am guessing it relates to both rapid groundwater recharge and relatively high shading rates in the Little Pilchuck

Commented [nlm190R189]: Moved it up will work on expanding in future

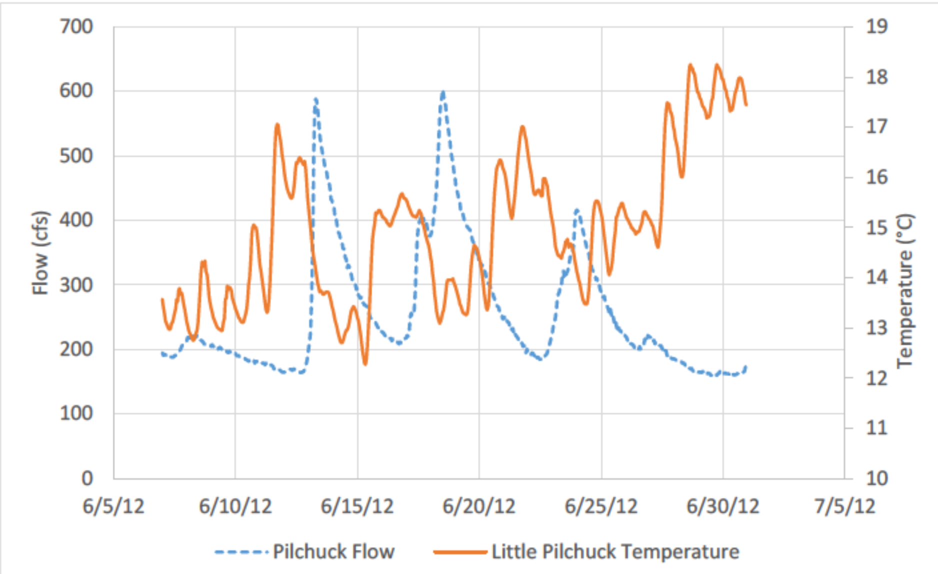

Figure 34. Relationship between June flow peaks (storms) and Little Pilchuck temperatures.

Although thermal loadings from permitted stormwater are of minimal size, all NPDES-permitted discharges that occur during the TMDL study period must be provided wasteload allocations.

Commented [SR(191]: It would be good to go over the findings in Appendix H and list in a table the likelihood of discharges from the various facilities Perhaps modify table 21

Commented [SR(192]: Would be good to add some text addressing new discharges at new sites, and transfer of WLAs to new industries moving into existing sites don't have the text developed for that just yet

Ecology's stormwater permits do not authorize discharges that would violate Washington State surface water quality standards, groundwater quality standards, sediment management standards or the human health-based criteria in the national Toxics Rule, as indicated in their permits.

Ecology's use-based temperature criteria (WAC 173-201A (Table 200(1)(c))) are expressed in 7-DADMax values. To be both consistent with these temperature criteria and practical (a receiving water could be affected by multiple stormwater outfalls with wide spatial distribution and controlled discharge rates), this TMDL expresses cumulative stormwater wasteload allocations as a 7-day average daily (7-DAD) loading value as measured at the TMDL monitoring points established in the TMDL study. Although the wasteload allocations incorporate seven daily values, they are expressed as a daily value and are consistent with the state's 7-DADMax criteria.

Appropriate BMPs required through stormwater permits for controlling pollutant loadings to surface waters are applied to each stormwater discharge to protect designated aquatic life uses. Ecology anticipates that there will be no additional TMDL-required conditions in stormwater permits, and compliance with the permit constitutes compliance with the goals of the TMDL. This TMDL does not contain any additional TMDL-related actions for stormwater permittees. Stormwater discharges may be considered for mixing zones as specified in WAC 173-201A-400, which should be applied in conjunction with the wasteload allocation in the previous paragraphs.

Load allocations

Load allocations (for nonpoint sources) and wasteload allocations (for point sources) are established in this TMDL to meet both the numeric threshold criteria and the allowances for human warming under conditions that are naturally warmer than those criteria.

Since it is predicted that system potential temperatures would not meet numeric water quality standards during the hottest period of the year throughout the Pilchuck River basin, there is a widespread need to achieve maximum protection from direct solar radiation. While all tributaries should also have system potential vegetation to ensure water quality standards are met for those streams, the lower two miles of each tributary are particularly important to the Pilchuck River achieving water quality standards.

The load allocation for the mainstem Pilchuck River below Menzel Lake Rd, and the two miles of each study area tributary nearest its mouth, is the potential shade that would occur from system potential mature riparian vegetation. *System-potential mature riparian vegetation* is defined as *that native vegetation which can grow and reproduce on a site, given: climate, elevation, soil properties, plant biology, and hydrologic processes.*

Because of the inherent uncertainties in estimating system potential shade, the 0.3°C that would normally be assigned to human sources is retained as a margin of safety and/or assigned to the stormwater and wastewater discharge point sources.

Load allocations for effective shade are quantified in Appendix F for the Pilchuck River and for the lower two miles of each tributary in the watershed. The load allocations are based on the estimated relationship between shade, channel width, and stream aspect at the maximum riparian vegetation condition (shown in Figure 36). The importance of shade decreases as the width of the channel increases.

Figure 37 presents predicted system potential and current effective shade on the Pilchuck River. Figure 38 shows the shade deficit, or difference between system potential and current shade, for the Pilchuck River within the study area.

The load allocations are expected to result in water temperatures that are equivalent to the temperatures that would occur under natural shade conditions. Because anthropogenic changes to stream temperature can result from causes other than the removal of shade, the implementation plan for this TMDL also includes a variety of measures to address channel structure, hyporheic flow, and other factors. Implementation of these measures, as well as system potential vegetation, will help ensure that water temperatures will approach natural conditions.

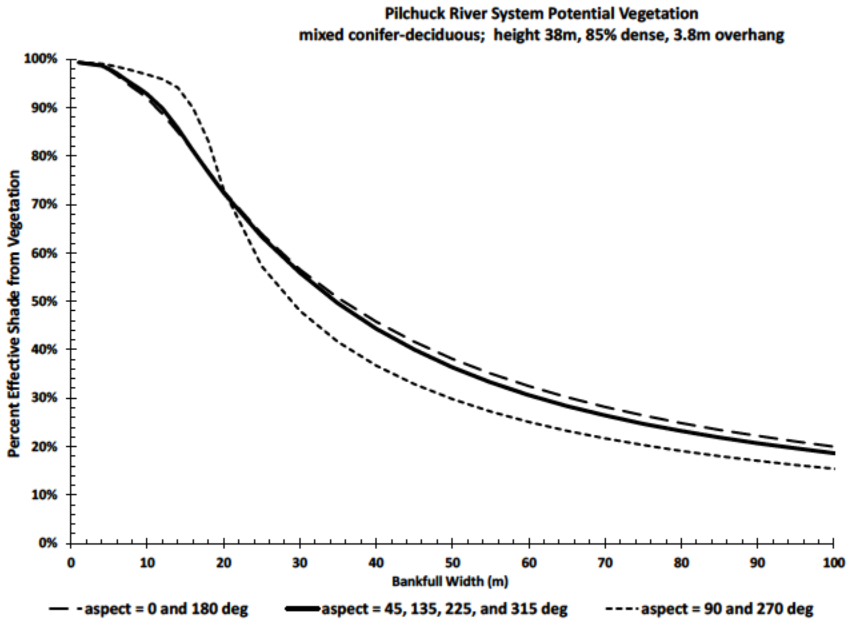

Figure 35. Effective shade vs bankfull width for system potential vegetation in the Pilchuck River.

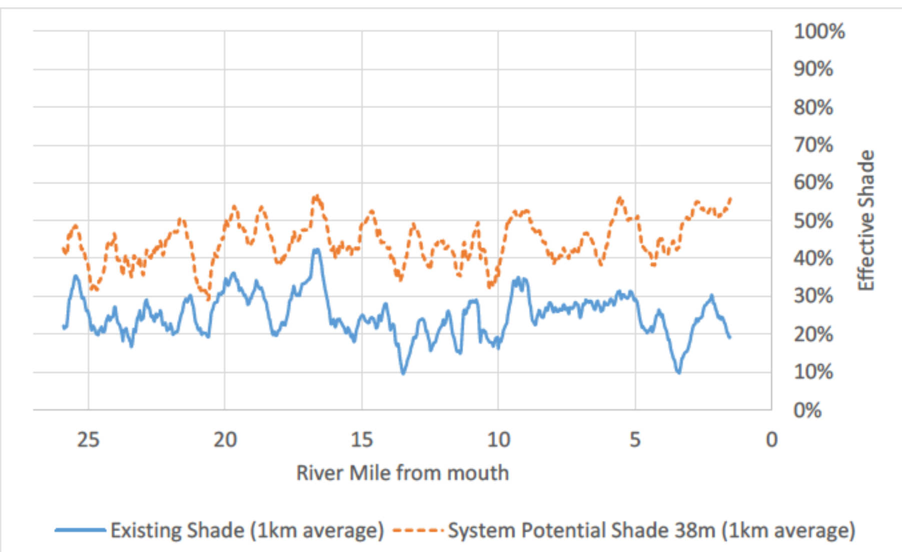

Figure 36. System potential shade on the Pilchuck River for August 15.

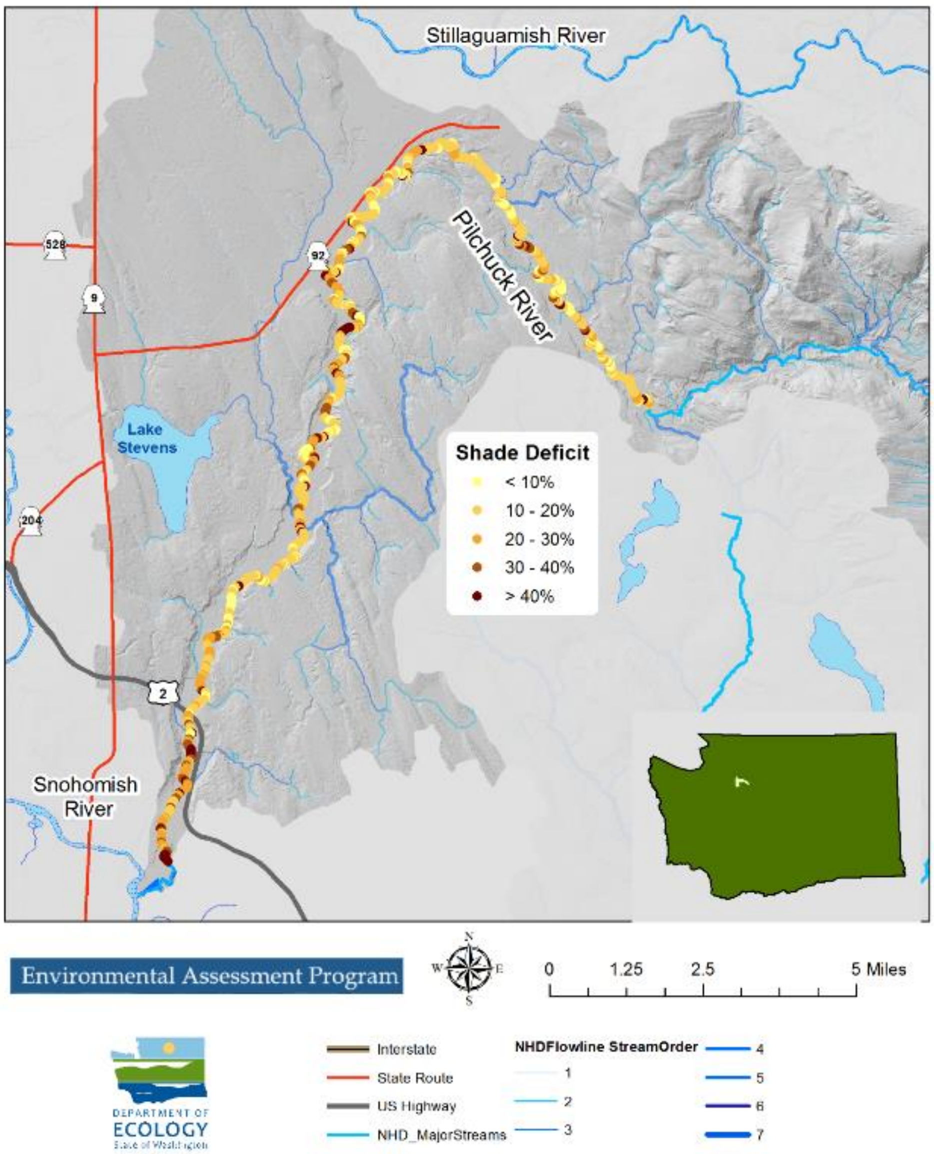

Figure 37. Shade deficit (system potential shade minus existing shade) for the Pilchuck River.

Seasonal variation

CWA section 303(d)(1) requires that TMDLs "be established at the level necessary to implement the applicable water quality standards with seasonal variations." The current regulation also states that determination of "TMDLs shall take into account critical conditions for streamflow, loading, and water quality parameters" [40 CFR 130.7(c)(2)]. Finally, section 303(d)(1)(D) suggests consideration of normal conditions, flows, and dissipative capacity.

The Pilchuck River Basin experiences seasonal variation with cooler temperatures occurring in the winter and warmer temperatures in the summer. The highest temperatures typically occur from mid-July through late-August. However, a more stringent criteria applies from February 15 to June 15 (13) and critical chinook spawning typically occurs in the month of September, when flows are at their lowest. For this reason, the critical season is defined as June 1 to September 30 to cover these shoulder season conditions. This time frame is used as the critical period for development of the TMDL.

Seasonal estimates for streamflow, solar flux, and climatic variables for the TMDL are taken into account to develop critical conditions for the TMDL model. The model was calibrated to a date from a period of June 7 to October 9 2012, which captured the warmest time of year and critical periods for both core summer salmonid and supplemental spawning. The study year (2012) ranked in the 95th percentile for air temperatures. The calibrated model was modified to represent critical stream flows (i.e., lowest 7-day average flows with 10-year recurrence interval or 7Q10) in order to develop load and wasteload allocations.

Load allocations from the summer model runs resulted in requiring the maximum riparian protection to the stream. The dynamic model confirmed that allocations would be protective throughout the summer season and during the hottest part of the supplemental spawning period. For point sources seasonal variation is taken into account, as described in the Wasteload Allocation section, through the use of dynamic wasteload allocations.

Reserve capacity for future growth

Given that temperatures exceed criteria, even under system potential conditions, there is very small capacity for future growth. However, future growth may occur under one of two conditions:

1. The temperature discharge occurs at or below the water quality criteria. None of the 0.3°C allowance is allocated to future growth, as it is already allocated to existing sources and margin of safety.
    a. Daily allocation for future growth in therms/day:

    $$Allocation_{future\ growth} = T_{crit} \times Q \times 97.1$$

    Where

    T_{crit} = The applicable temperature criterion
    Q = future discharge in cubic feet per second
    97.1 = conversion factor to transform the units to therms/day
2. By replacing a permitted heat load source that was assigned an allocation in this TMDL.

Margin of safety

The margin of safety accounts for uncertainty about the pollutant loading and water-body response and must be included in all TMDLs to ensure water quality standards are met, despite these uncertainties. In this TMDL, the margin of safety is addressed in two ways.

Implicit

- The 95th percentile of the highest 7-day averages of daily maximum air temperatures for each year of record at the Monroe and NCDC Summary of the Day Station WA457507 was combined with the lowest 7-day average flows with recurrence intervals of 10 years (7Q10) to represents a reasonable worst-case condition for prediction of water temperatures in the Pilchuck River watershed. The combination represents a recurrence interval of > 10 years.
- The lowest 7-day average annual flows with recurrence intervals of 10 years (7Q10) were used to evaluate reasonable worst-case conditions for discharge of point source effluent.
- The 7Q10 used to calculate temperature wasteload allocations for the Granite Falls WWTP was scaled down by a factor of 0.85 from the downstream USGS gage. This factor is conservative given that the two low-flow measurements available to compare these locations had ratios of 0.86 and 0.95.
- The daily maximum values are used to set the TNPDES and WLA values for point sources. Daily maximum values are biased high compared to the 7-DADmax values set in the water quality standards.
- Model uncertainty assessment for prediction of water temperature in existing conditions compared to system potential conditions revealed a variance between scenarios of 0.16°C root mean square error (RMSE). This is less than the 0.3°C allowable change from natural conditions.
- Model bias evaluation shows no evidence of systematic over- or under-prediction of temperature. There also is no evidence of a trend in error over the length of the river.
- Temperature load allocations are set to the effective shade provided by 100-year-old riparian vegetation.
- Implementation will include additional measures beyond riparian shade that should contribute to lower stream temperatures, such as instream structures creating pools that connect with hyporheic flow, and wetland restoration creating improved groundwater connection.

Explicit

- 10% of the temperature load capacity is set aside as an explicit margin of safety.

Conclusions and model findings

- Under the current riparian status, the Pilchuck River maximum water temperature is expected to average 22.1°C and in some locations to exceed the 23°C lethal threshold to salmonids during critical low-flow (7Q10) and 90th percentile climate conditions.
- A buffer of mature riparian vegetation along the banks of the Pilchuck River is expected to decrease the average daily maximum temperature. For the critical low-flow scenario, the daily maximum temperature across the stream length could be decreased by about 0.9ºC (1.6ºF) compared to current conditions.
- The changes in microclimate associated with mature riparian vegetation could further lower the daily average maximum water temperature by about 0.2ºC.
- If restoration activities in the tributaries and headwater result in waters that meet the numeric temperature standards, a further reduction of 0.7ºC is expected.
- With all management scenarios in place, temperatures are expected to remain significantly below the lethal threshold, averaging 20.3°C during critical conditions. These temperatures are still above the numeric water quality criteria.
- With all management scenarios in place, the overall decrease in the average maximum stream temperature for the simulated critical condition was 1.8ºC for 8/5/12. While the river would still reach temperatures in late July or August above the maximum values established in the numeric water quality criteria, the cooling will be significant for the designated beneficial uses of these waterbodies.
- With all management scenarios in place, the overall decrease in the average maximum stream temperature for the simulated supplemental spawning was 1.2ºC (6/13/12) and September condition was 1.9 ºC (9/1/12). With these reductions the river would remain below the fish embryo lethality threshold (17.5 ºC) and meet the respective 7-DADMax criteria (13 and 16 ºC) in almost all of the river, with the exception of the lowest reaches.
- Overall, Ecology found the study data to be of acceptable quality and useable based on Ecology’s credible data policy and the study objectives.
- The summer of 2012 exhibited warmer than average air temperatures (95th percentile for 7 day average max) and relatively average river low-flow levels.
- The 7-day average daily max temperatures during 2012 did not meet (are above) water quality criteria at all sites monitored in the watershed, including the upstream boundary and tributaries. The steepest increase in longitudinal temperature on the river occurred at the upstream end of the study area between Menzel Lake Rd (~RM 25) and Robe Menzel Rd (~RM 21), ~2.7 ºC over ~4 river miles.
- Significant groundwater discharge to the Pilchuck River was inferred from results of flow balance surveys and was observed in the field, primarily as diffuse seepage from banks, particularly where the river channel intersected the contact of the glacial till with the overlying sediments.

- Hyporheic flow of river water through bottom sediments and gravel bars was observed throughout the study area. The estimated amount of hyporheic flow in the Pilchuck River is predicted to be a significant mitigating factor for temperature.
- The primary source of heat loading is direct solar shortwave radiation. Shade from riparian vegetation is the largest mitigating factor for reducing stream temperatures.

Recommendations

- Increasing shading to the lower half of the Pilchuck River (~RM 0 to 12) should be the top priority. These improvements are particularly important for avoiding the lethal threshold (23 ºC) at peak temperatures and the fish embryo lethality threshold (17.5 ºC) during the critical Chinook spawning month of September.
- Increasing riparian shade along the rest of the river is also very important for improving thermal habitat and avoiding lethal conditions for fish.
- Riparian restoration of tributaries that are high value for salmonid use should also be a priority. It is often easier and faster to establish vegetation to shade narrower tributary streams.
- Hyporheic exchange flows and groundwater discharges are important in maintaining the current temperature regime and reducing maximum daily instream temperatures.
    - Factors that influence hyporheic exchange flow include the vertical hydraulic gradient between surface and subsurface waters as well as the hydraulic conductivity of streambed sediments.
    - Activities that reduce the hydraulic conductivity of streambed sediments could increase stream temperatures.
    - Management activities should reduce upland and channel erosion and avoid sedimentation of fine materials in the stream substrate.
- Protecting and restoring channel structure and habitat features at or near cold water refuges is necessary to provide thermal relief during peak summer temperatures.
- Load and wasteload allocations are needed for municipal stormwater, WSDOT stormwater, general stormwater permit holders, tributaries, and other nonpoint sources. These load and wasteload allocations will prevent temperature impairments throughout the Pilchuck River.
- Establish/continue long-term temperature monitoring in the Pilchuck River to track trends over time.
- Confirm cooling trend between the Granite Falls WWTP facility and outfall to the Pilchuck River with continuous temperature monitoring.
- Quantify hyporheic flow fraction, depth, and thermal properties to understand impact of hyporheic restoration over multiple scales.
- Preserve/restore groundwater baseflow, off channel wetlands, and areas with hyporheic function. These features are important for mitigating high instream temperatures.

Dissolved Oxygen TMDL Analysis and Allocations

System potential conditions

The calibrated QUAL2Kw model was used to estimate the pH that would be expected to occur under system potential conditions. System potential conditions are conditions that do not include human modifications to riparian vegetation, or anthropogenic nutrient sources. The system potential condition also serves as an estimate of natural conditions.

To estimate system potential DO conditions, the QUAL2Kw model was modified in the following ways:

- Point source effluent discharges were removed from the simulation.
- Shade inputs were changed to reflect system potential riparian vegetation.
- The upstream end of the model domain and tributary boundary conditions were modified to reflect estimated system potential temperature, DO, pH, and nutrient loads.
- Groundwater phosphorus concentrations were set at 25^{th} percentile of the study results (6.4 ug/L SRP); groundwater ultimate BOD was left at estimated 2012 levels to represent wetland/forest carbon loading.

Complete documentation of the model inputs and values used can be found in Appendix E under the heading "System Potential Conditions Model Inputs."

It was not possible to accurately include all human modifications to the river system in the model. Some known or suspected human modifications were omitted, including changes to groundwater/hyporheic flow and nutrient spiraling/loading from system potential salmon runs. Analysis of these factors is outside the scope of this study and represent very complex environmental processes that would be difficult to estimate within a reasonable level of certainty.

System potential conditions were simulated continuously for the time period from June 7th to October 9th. Figures 32-33 present the simulation results for system potential conditions. This period captures the most critical conditions during the year for DO, including low flow, high temperatures, and maximum accrued periphyton biomass.

Compliance with standards

During the 2012 study year, the model predicted that the entire river would fail to meet the 1-day minimum DO criterion for Core Summer Salmonid Habitat (9.5 mg/L) during the month of August. Much of the river is predicted to fail to meet the 9.5 mg/L criterion during the months of July and September. The lower river is predicted to fail to meet the criterion in June, however no DO data was collected during June to confirm this, so these predictions carry greater uncertainty. The lower river was also predicted to fall low enough to not meet the lesser beneficial use of Spawning, Rearing, and Migration, criterion of 8 mg/L in August (Figure 31).

The system potential model was run with upstream flows from a 7Q10 critical low-flow year (2004) to compare minimum DO to TMDL scenarios (Figure 32). The minimum DO was increased by 0.6 mg/L for the most critical day (8/5/12). However, much of the river still failed to meet the 9.5 mg/L criterion during the months of July and August.

As with temperature, because 2004 flows were closer to average in June and September, an additional system potential model run was conducted with flows from 2009 (near 7Q10 flows for these specific months). Figure 33 depicts this run and shows that most of the river would likely meet the 9.5 mg/L criterion from September to early October.

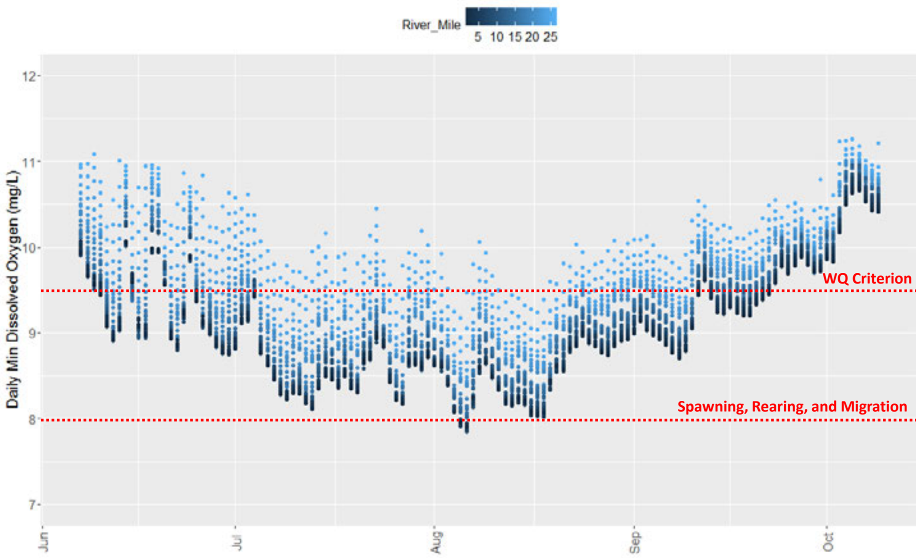

Figure 38. Existing 2012 model predicted daily minimum DO compared to WQ criteria.

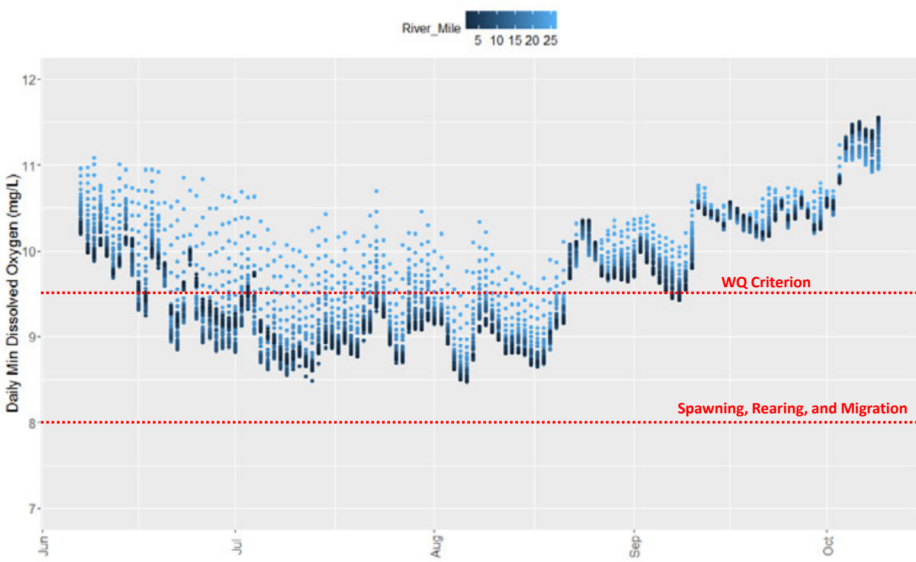

Figure 39. System potential model predicted daily minimum DO with 2004 flows.

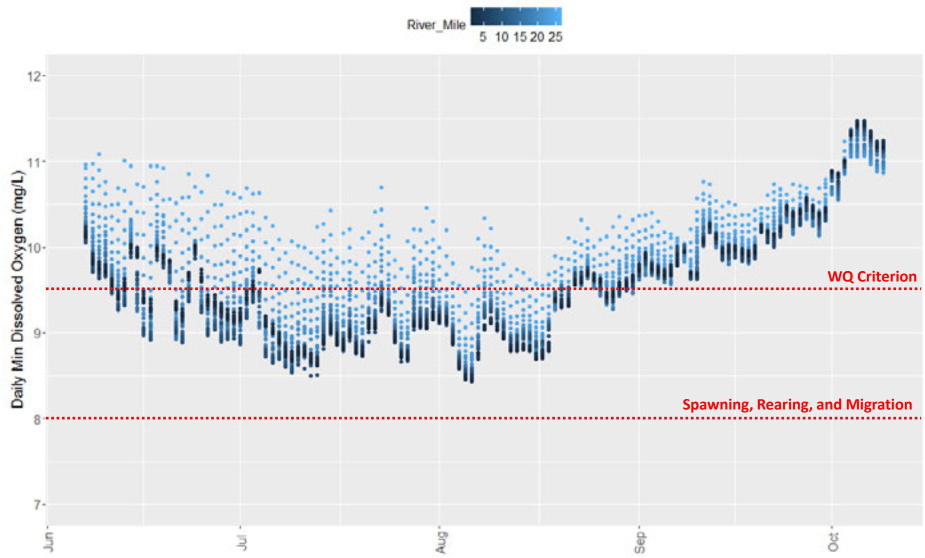

Figure 40. System potential model predicted daily minimum DO with 2009 flows.

Loading capacity

The loading capacity of a river system is defined as the amount of a pollutant that can be added to the river without causing an exceedance of the water quality standards. Because DO is predicted to exceed the numeric criteria during the critical season even under system potential conditions, the loading capacity for DO in this TMDL is based on ensuring that the total human impact does not exceed 0.2 mg/L change to DO.

The calibrated QUAL2Kw model was used to estimate the assimilative load capacity for phosphorus and BOD in the Pilchuck River, which is the basis for the load and wasteload allocations assigned in this TMDL. For phosphorus, the allocations are provided in SRP and not total phosphorus. The basis for using SRP in this TMDL is:

1. Travel times are relatively fast in the system (<1.5 days) and the calibrated hydrolysis rate of organic/particulate phosphorus appears to be relatively slow (10%/day). This results in relatively little particulate phosphorus being converted to SRP in the river. In the TMDL model the river is at ~2 ug/L of organic phosphorus downstream of the treatment plant, which means <0.3 ug/L of SRP are added diffusely over the course of ~19 river miles.
2. The WWTP effluent (primary source of P loading) contained almost entirely SRP, with very little organic phosphorus in the samples analyzed.
3. The TMDL model is conservative in that it assumes ~30% particulate P, even though sample results have been much less with current treatment

4. A sensitivity analysis (see table and graph below) shows that:
   a. DO in the river is not impacted by an increase in organic P and total P from the WWTP (with SRP held constant).
   b. DO is significantly impacted by an increase in SRP from the WWTP (with TP held constant).

Table 25. Phosphorus concentrations for SRP vs total P sensitivity analysis.

In the TMDL model the WWTP is set as:	
60	ug/L OrgP
125	ug/L SRP
185	ug/L TP
For the high TP scenario (a) the WWTP is set as:	
120	ug/L OrgP
125	ug/L SRP
245	ug/L TP
For the high SRP scenario (b) the WWTP is set as:	
0	ug/L OrgP
185	ug/L SRP
185	ug/L TP

Figure 41. Plot showing sensitivity of DO in the TMDL model to increases in total P and SRP from the WWTP.

The Pilchuck River typically has low concentrations of SRP during the critical period. Because DO and pH are tied to algal productivity, and because productivity is limited by SRP availability, any input of SRP will likely have an impact on DO and pH.

To protect DO, loading capacities have been evaluated for biochemical oxygen demand (BOD) as well as for soluble reactive phosphorus (SRP). The load capacities for both BOD and SRP rely on the loading of the other. In the Pilchuck River model, SRP loading has a greater impact on DO compared to BOD, so the load capacity for the purposes of the TMDL is set as the existing BOD loading and a reduction in SRP loading to meet WQ standards (Figure 34).

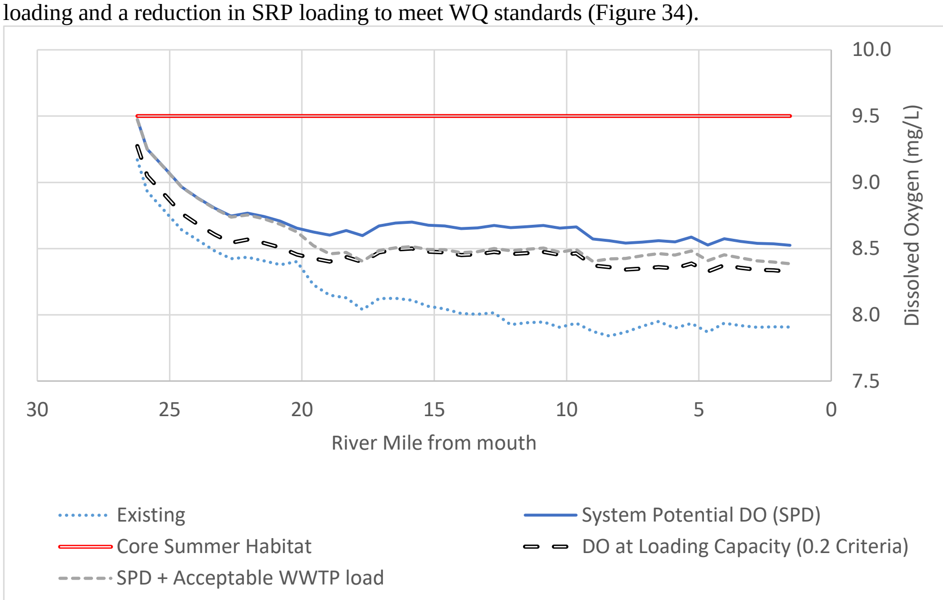

Figure 42. Longitudinal DO profile illustrating loading capacity and maximum allowable loading from the Granite Falls WWTP plant.

The loading capacity for this TMDL was evaluated within the critical conditions model based on WWTP reductions needed to meet the 0.2 criterion and existing and potential discharges from point and nonpoint sources. Two estimates of loading capacity were derived from this analysis:

1. Daily SRP load capacity at baseflow (<75 cfs) of ~2.6 lbs SRP/day.
2. Seasonal SRP load capacity from June 1 to September 30 of ~1,811 lbs SRP/season.

The details of how these loading capacities were derived are described in further detail in the allocations section of the report.

Wasteload allocations

Table 24 lists the discharges in the *Pilchuck River Temperature and DO TMDL* study area that have National Pollutant Discharge Elimination System (NPDES) permits. Appendix H provides a more detailed accounting of individual permittees within the watershed, including current activity level and potential to discharge to surface water.

Table 26. Dischargers in the watershed covered by NPDES Permits.

Receiving Waterbody Name	Permittee Name	Permit #	Permit Type
Pilchuck River	Granite Falls WWTP	WA0021130	Municipal NPDES IP
Pilchuck Watershed	Numerous; transient		Construction SW GP
Little Pilchuck	Central Steel	WAR012091	Industrial SW GP
Little Pilchuck	Northwest Auto Recyclers	WAR303981	Industrial SW GP
Pilchuck River	UPF Washington LLC (NEPA Pallet & Container)	WAR000752	Industrial SW GP
Pilchuck Watershed	Snohomish County- Phase 1	WAR044502	Municipal SW
Pilchuck Watershed	City of Granite Falls- Phase 2	WAR045517	Municipal SW
Pilchuck Watershed	City of Lake Stevens- Phase 2	WAR0021130	Municipal SW
Pilchuck Watershed	City of Snohomish- Phase 2		Municipal SW
Pilchuck Watershed	WSDOT	WAR043000	Transportation SW GP
Trib of Pilchuck?	Pilchuck Sand & Gravel Inc	WAG503379	Sand and Gravel GP
Groundwater	Riverside Sand & Gravel	WAG 503086	Sand and Gravel GP
Facility inactive	Granite Falls Quarry L Matheson	WAG503085	Sand and Gravel GP
Groundwater	Lake Industries Menzel Lake Gravel	WAG503312	Sand and Gravel GP
Unknown	Jaxico Real Estate Investment Group LLC	WAG994258	Sand and Gravel GP
Ditch to Little Pilchuck	Thomco Aggregate LLC	WAG503027	Sand and Gravel GP
Pond	Premier Pacific Properties (Island Construction Site & Utilities)	WAG503327	Sand and Gravel GP
EF Little Pilchuck	Concrete Norwest Getchell Pit	WAG503166	Sand and Gravel GP
Pond next to Pilchuck River	D&D Excavating (Marysville Const & Paving Co)	WAG503046	Sand and Gravel GP

Commented [SR(193]: Just making a note right now to revisit this section with regard to the need for P-removal in stormwater discharges If it were a lake P TMDL we would certainly be doing that but in the case of DO the value/need for that is much less clear

The primary point source of nutrient loading to the Pilchuck River is the Granite Falls WWTP, which is the only constant permitted discharge. The WWTP commonly discharges nitrogen and phosphorus levels greater than 100x the concentration in the river, although the current summer effluent flow levels are relatively small (less than 1 cfs).

Because the DO impact of nutrient loading dissipates downstream of the source, the loading capacity in the Pilchuck River TMDL can be assigned to successive sources on downstream segments of the river without impairing DO. Table 25 and Figure 40 describe and illustrate the loading segments used in the TMDL.

In the case of the Granite Falls WWTP, the impact of phosphorus and BOD loading dissipates fairly gradually, meaning the available loading capacity increases gradually, the further you move downstream from the point of greatest impact (Figure 39).

The loading capacity for each downstream section is partially "renewed" and can then be assigned to existing or potential sources, such as a facility, permit category, or tributary.

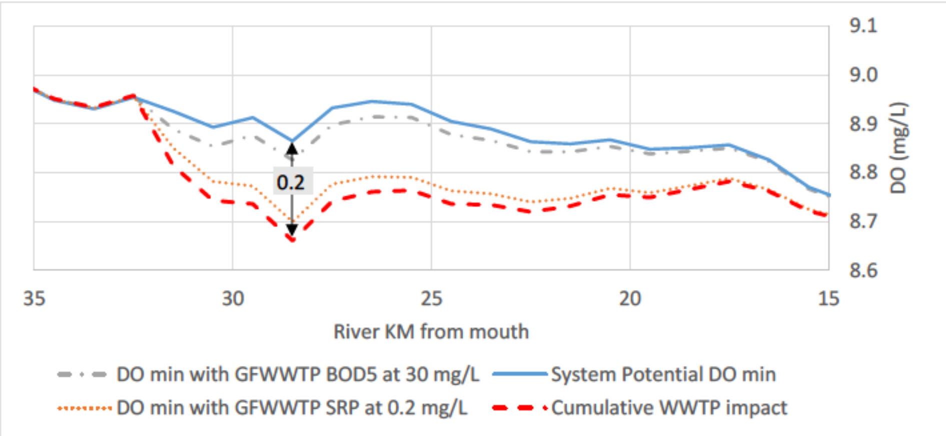

Figure 43. Example of impact to DO below Granite Falls WWTP at specific loading scenario.

Table 27. Load allocation segmentation of the Pilchuck River used for this TMDL.

Reach Name	Upstream end of reach	Downstream end of reach	Downstream Description/ Location
Menzel	42 km (Menzel Lake Rd)	35.5 km	Robe Menzel Rd; PIL21.5
Granite Falls	35.5 km	31.8 km	Granite Falls WWTP outfall
SR 92	31.8 km	24.8 km	64th St NE
Lochsloy	24.8 km	19.5 km	28th Pl NE
Russell Rd	19.5 km	14 km	Upstream of Little Pilchuck confluence
Little Pilchuck	Entire basin	Entire basin	Confluence with Pilchuck
Dubuque Creek	Entire basin	Entire basin	Confluence with Pilchuck
Machias	19.5 km	10 km	Dubuque Rd
Three Lakes	10 km	6.6 km	Three Lakes Rd
Snohomish	6.6 km	2 km	Pilchuck Recreation Area

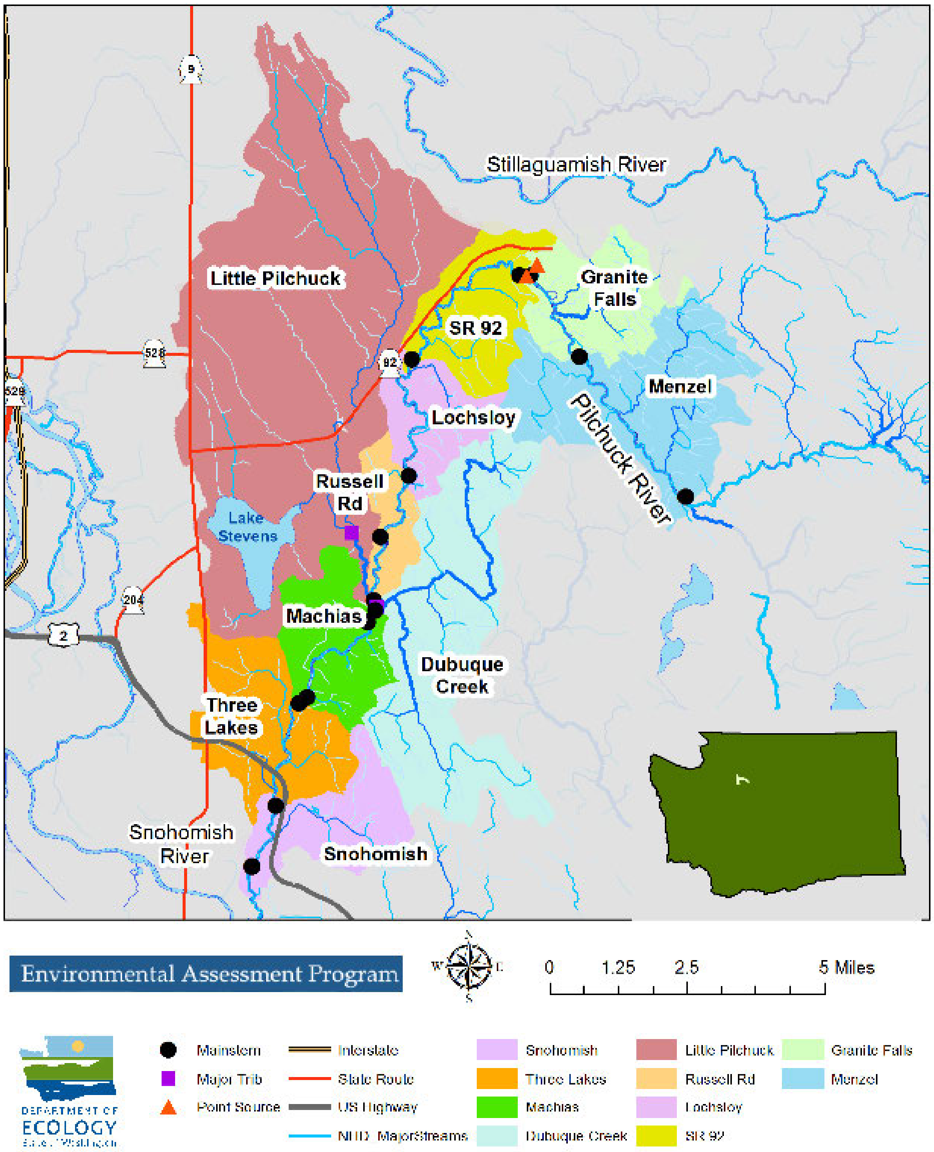

Figure 44. TMDL allocation segmentation within the Pilchuck River watershed.

This TMDL assigns daily phosphorus wasteload allocations, in lbs SRP/day, during summer baseflow conditions (river flow of less than 75 cfs). These daily allocations were designed using the following process:

1. Leave the Granite Falls WWTP BOD loading at current permit levels.
2. Set the Granite Falls WWTP phosphorus at loading that causes no greater than 0.2 mg/L change to downstream DO levels in the Pilchuck River.
3. Set stormwater and general permit WLAs upstream of Granite Falls WWTP at very low or zero loading so as not to increase cumulative impact near WWTP.
4. Allocate "renewed" loading capacity to downstream segments based on size of drainage area and distance downstream from WWTP outfall.
5. Within each segment the "renewed" loading capacity is allocated to the municipal stormwater permittees, based on the size of drainage area.

The "renewed" baseflow capacity is allocated to the municipal stormwater permittees to allow for stormwater infrastructure that discharges at baseflow, in between runoff events. In some situations, infiltrated or treated stormwater can be discharged gradually or in batches via a pump station or other control structure. These types of discharges can add cooler baseflow to the river, depending on storage method and retention time. Since a steady increase in baseflow and decrease in temperature is beneficial to aquatic life, some phosphorus allocation is provided to allow for this option, assuming the temperature WLAs outlined in this TMDL are also met.

The TMDL does not set a daily phosphorus load limit for permitted sources when river flows are greater than 75 cfs; given that flow conditions, runoff loading, and daily load capacity are dynamic under these conditions. To account for dynamic conditions and impacts over the season, the TMDL also allocates seasonal phosphorus allocations, in lbs SRP/season. The seasonal WLAs limit the amount of algae growth over the course of the season due to phosphorus uptake during both baseflow and storm events.

The dynamic 124 day QUAL2Kw model of the Pilchuck River allows for analysis of the impact of variable phosphorus loading over the course of the summer. For phosphorus, both the daily and seasonal allocations only apply during the critical season from June 1 to September 30 (see *Seasonal Variation*).

Commented [PP(194]: This is all you say about this Was this model used to calculate the seasonal WLAs? More explanation is needed about how the values in Table 26 were derived

Table 26 includes both daily baseflow and seasonal phosphorus wasteload allocations for all individual and general NPDES permits within the TMDL study area. Because construction stormwater, industrial stormwater, and sand and gravel general permits can be short term for an individual permittee (construction is completed or facility becomes inactive), one aggregate wasteload allocation is assigned to each general permit, and not to individual facilities/permittees. Figure 41 shows the division of wasteload allocations by permit and reach.

Although the Granite Falls WWTP is assigned a daily and seasonal WLA, it is recommended that only a seasonal limit be included in the permit. Operationally there is considerable variability in advanced treatment nutrient concentrations due to factors such as sludge age, chemical dosing rates, etc. and daily limits are not practical to implement unless set at some high value (say 95% of performance). However these high daily limits are less meaningful in the context of impacts to the river, as the effects of nutrient loading to periphyton growth accumulate over the course of weeks and therefore monthly or seasonal limits are more appropriate.

Table 28. Daily (baseflow only) and seasonal point source wasteload allocations for SRP in the Pilchuck River watershed

Commented [PP(195]: I like this approach, but think a full season may be too long I don't see the justification If you have a spike of P, how long would the effects last? Or a long period of high followed by a long period of low A rolling average of 7 days might be a better approach (to pull a number out of the air), based on the model's response to TP changes

Reach	Granite Falls WWTP	Snohomish County Phase 1	City of Granite Falls Phase 2	City of Lake Stevens Phase 2	City of Snohomish Phase 2	WSDOT	Construction Stormwater General	Industrial Stormwater General	Sand and Gravel General	Future Individual Permits	Total Reach Allocation
Seasonal WLA (lbs SRP/season); Season = June 1 to September 30											
Menzel	*	50.40	*	*	*	n/a	2.8	2.8	0	0	56
Granite Falls	*	28.86	2.59	*	*	1.85	1.85	1.85	0	0	37
SR 92	79	36.00	7.2	*	*	7.2	7.2	7.2	0	0	144
Lochsloy	*	19.35	*	*	*	0.25	2.00	2.00	0.25	2.00	25.8
Russell Rd	*	12.75	*	*	*	n/a	0.75	0.75	0	0.75	15
Little Pilchuck	*	157.8	*	27.84	*	14.8	14.8	14.8	2.5	14.8	248
Dubuque Ck	*	76.64	*	*	*	*	5.75	5.75	1.92	5.75	95.8
Machias	*	26.9	*	0.34	*	*	2.0	2.0	0.7	2.0	34
Three Lakes	*	91.35	*	9.45	3.15	8.4	8.4	8.4	1.4	8.4	140
Snohomish	*	102.0	*	n/a	10	*	8	8	3	8	140
Total	**79**	**602**	**10**	**38**	**13**	**33**	**54**	**54**	**10**	**42**	**935**
Daily WLA at baseflow of <75 cfs (lbs SRP/day); only applies from June 1 to September 30											
Menzel	*	0.022	*	*	*	*	0	0	0	0	0.02
Granite Falls	*	0.014	0.001	*	*	0	0	0	0	0	0.02
SR 92	0.65	0.010	0.01	*	*	0	0	0	0	0	0.67
Lochsloy	*	0.022	*	*	*	0	0	0	0	0	0.02
Russell Rd	*	0.013	*	*	*	*	0	0	0	0	0.01
Little Pilchuck	*	0.176	*	0.031	*	0	0	0	0	0	0.21
Dubuque Ck	*	0.080	*	*	*	*	0	0	0	0	0.08
Machias	*	0.280	*	0	*	*	0	0	0	0	0.28
Three Lakes	*	0.160	*				0	0	0	0	0.16
Snohomish	*	0.140	*	*	0.02	*	0	0	0	0	0.16
Total	**0.65**	**0.92**	**0.01**	**0.03**	**0.02**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.63**

*no potential to discharge in this reach

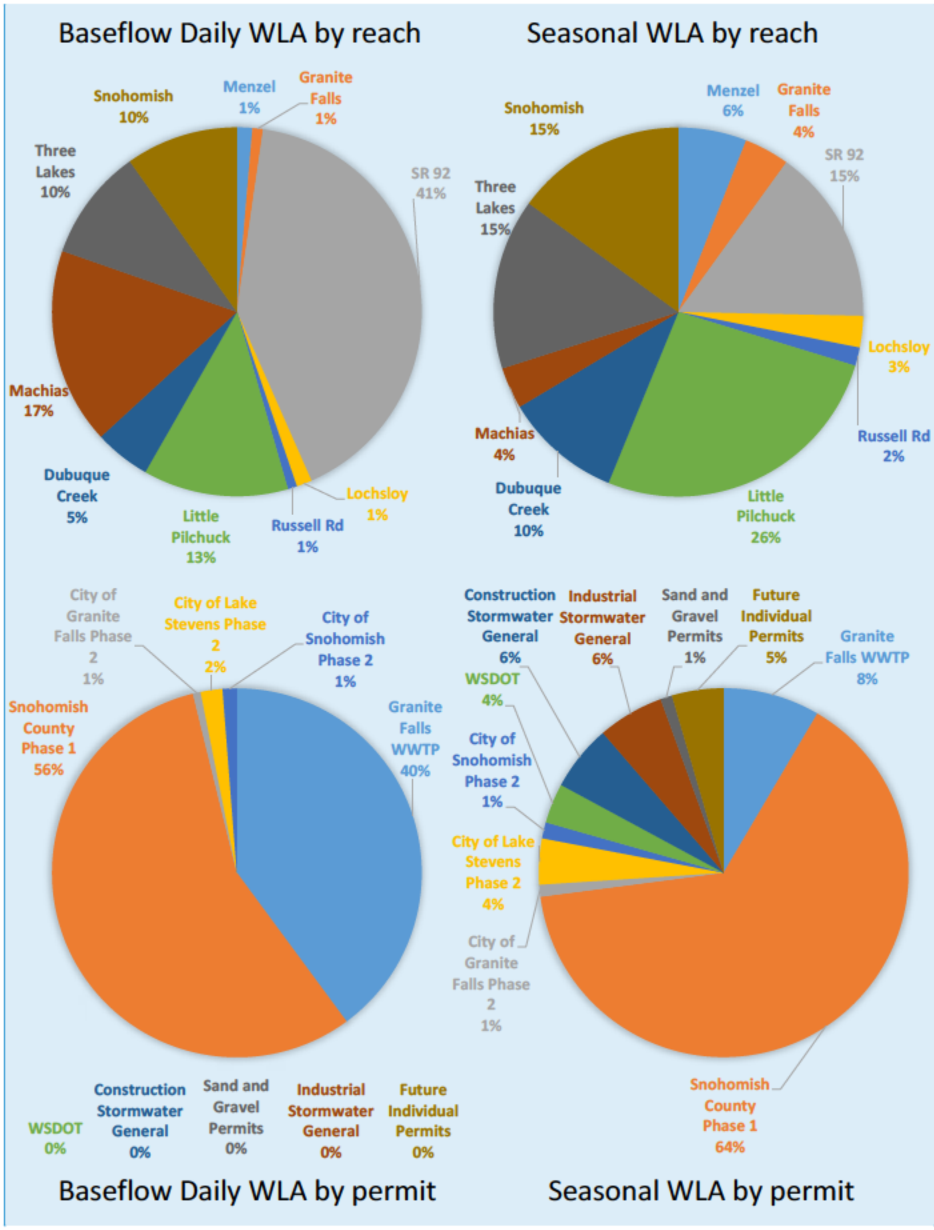

Figure 45. Pie charts depicting division of WLA by permits and reach.

Commented [NE(196]: Pie charts are not my favorite chart type, but this figure works well If you were unhappy with these charts for some reason, I think back-to-back historgrams might illustrate the daily vs seasonal changes well also

It takes a little while to figure out that the labels are below the bottom pies Consider moving the labels were above each pie for consistency

Commented [SR(197]: Let's talk more about the 0% daily caption Might we reference the relatively small allocation differently?

Load allocations

Nonpoint sources of phosphorus in the Pilchuck watershed are assigned a load allocation, based on available loading capacity of the stream and taking into account wasteload allocations for point sources. The upper watershed of the Pilchuck River is primarily undeveloped and forested. Summer flows in the river come from a combination of rainwater and groundwater, which are typically low in phosphorus. 2012 study results at the upper watershed study boundary had an average of 8 µg/L SRP. In the Pilchuck River, observed surface and groundwater phosphorus concentrations were typically low (~10 ug//L SRP) and assumed to be only slightly elevated above undisturbed conditions.

Given that the loading capacity is very limited upstream and immediately below the WWTP, the TMDL designates a 25% reduction in nonpoint phosphorus sources within these reaches. Below the Lochsloy reach, loading capacity is sufficient to allow for current estimated nonpoint phosphorus loading levels.

However, future nonpoint loading within these reaches must not increase phosphorus loading above the load allocations assigned in Table 27.

Commented [SR(198]: Nuri as previously written I felt the reader had to take it on faith that the upper watershed was low in SRP I tried to put in a number that would establish that fact I do not like what I wrote but took a stab at it If you don't like this, can you think of any EAP studies or other work that could be cited to show that 10 ug/L SRP is relatively low and a 25% reduction makes sense? When I looked at the raw data it seemed like the surface water boundary condition had the highest OP levels Did not see the groundwater data in Appendix D to average downstream numbers so I could not look at this any further and recommend text to insert

Commented [SR(199]: I am going to go back and read the report from the beginning Somewhere it would be good for me to better understand why the loading capacity is notably low upstream but not downstream below SR 92 allocation segmentation I've been jumping around and it is affecting my ability to make helpful comments

Table 29. Load allocations for nonpoint phosphorus sources in the Pilchuck TMDL study area.

Reach Name	Applicable nonpoint sources from WQ model	Nonpoint Reduction	LA baseflow (lbs/day)	Seasonal LA (lbs SRP)
Menzel	Groundwater (GW)	25%	0.08	63.0
Granite Falls	GW; Four Minor Tribs; T19.3	25%	0.15	88.0
SR 92	GW; Gardner Lake Tr b; KHF tr b; T15.3	25%	0.13	98.2
Lochsloy	GW; Connor Lake Tr b; T14.6 T11.5	25%	0.08	64.5
Russell Rd	GW; T10.7	None	0.09	71.1
Little Pilchuck	Little Pilchuck Creek	None	0.15	252.1
Dubuque Ck	Dubuque Creek	None	0.02	37.2
Machias	T7.9, T7.3	None	0.11	84.8
Three Lakes	Scott Creek; T6	None	0.06	51.0
Snohomish	Golf course and Bunk Foss Creek	None	0.08	66.5
Total =				

In addition to phosphorus load allocations, full mature system potential shade is needed to improve DO. Thus the load allocations developed in the Temperature section of this TMDL also apply to the DO TMDL.

Seasonal variation

CWA section 303(d)(1) requires that TMDLs "be established at the level necessary to implement the applicable water quality standards with seasonal variations." The current regulation also states that determination of "TMDLs shall take into account critical conditions for streamflow, loading, and water quality parameters" [40 CFR 130.7(c)(2)]. Finally, section 303(d)(1)(D) suggests consideration of normal conditions, flows, and dissipative capacity.

The Pilchuck River Basin experiences seasonal variation that impacts DO levels. In the winter, DO levels are significantly higher as the cooler water can hold more oxygen, more upstream flow allows for a greater loading capacity of phosphorus, and deeper water coupled with weaker solar radiation leads to very little periphyton growth. In the summer, warm water holds less oxygen, flow is low and loading capacity reduced, and shallow water coupled with peak solar radiation can lead to rapid periphyton growth.

The combination of lowest flows and highest temperatures typically occurs in July and August. However spawning can occur in the months of June and September and these months can sometimes have lower flows and higher temperatures. For this reason, the critical season is defined as June 1 to September 30 to cover these shoulder season conditions. This time frame is used as the critical period for development of the TMDL.

Seasonal estimates for streamflow, solar flux, and climatic variables for the TMDL are taken into account to develop critical conditions for the TMDL model. The model was calibrated for a period of June 7 to October 9 2012, which captured the warmest time of year, lowest flows, and lowest DO. The study year (2012) ranked in the 95^{th} percentile for air temperatures. The calibrated model was modified to represent critical stream flows (i.e., lowest 7-day average flows with 10-year recurrence interval or 7Q10) in order to develop load and wasteload allocations.

Reserve capacity for future growth

Given that DO levels are below criteria, even under system potential conditions, there is a very small capacity for future growth. However, future growth may occur under one of two conditions:

1. By replacing a phosphorus load source that was assigned an allocation in this TMDL.
2. The TMDL includes some reserve for individual discharge permits, provided there is no discharge of phosphorus to Pilchuck River at baseflow (< 75 cfs) and cumulative phosphorus loading from June 1 to September 30 is less than the seasonal wasteload allocation outlined in Table 26.

Margin of safety

The margin of safety accounts for uncertainty about the pollutant loading and water-body response and must be included in all TMDLs to ensure water quality standards are met, despite these uncertainties. In this TMDL, the margin of safety is addressed in two ways.

Implicit

- The 95th percentile of the highest 7-day averages of daily maximum air temperatures for each year of record at the Monroe and NCDC Summary of the Day Station WA457507 was combined with the lowest 7-day average flows with recurrence intervals of 10 years (7Q10) to represents a reasonable worst-case condition for prediction of DO in the Pilchuck River watershed. The combination represents a recurrence interval of > 10 years.

- The lowest 7-day average annual flows with recurrence intervals of 10 years (7Q10) were used to evaluate reasonable worst-case conditions for discharge of point source effluent.
- The 7Q10 used to calculate DO wasteload allocations for the Granite Falls WWTP was scaled down by a factor of 0.85 from the downstream USGS gage. This factor is conservative given that the two low-flow measurements available to compare these locations had ratios of 0.86 and 0.95.
- Model uncertainty assessment for prediction of DO in existing conditions compared to system potential conditions revealed a variance between scenarios of 0.08 mg/L root mean square error (RMSE). This is less than the 0.2 mg/L allowable change from natural conditions.
- Model bias evaluation shows no evidence of systematic over- or under-prediction of DO. There also is no evidence of a trend in error over the length of the river.
- The calibrated model slightly over predicts phosphorus uptake downstream of the WWTP and thus slightly under predicts phosphorus loading capacity.

Explicit

- Currently no explicit MOS, could add one.

Conclusions and model findings

- DO in the Pilchuck River is sensitive to soluble reactive phosphorus (SRP). Small inputs of SRP can have significant impacts to DO.
- The SRP discharged by the Granite Falls WWTP has an impact of up to 0.75 mg/L on daily minimum DO in the downstream reaches of the river.
- The shade produced by system-potential mature riparian vegetation is expected to improve daily minimum DO values by up to 0.55 mg/L.
- Background dissolved nutrient concentrations are relatively low in the river (<10 ug/L orthophosphate; <100 ug/L dissolved inorganic nitrogen).
- The analysis of N:P ratios indicate that the limiting nutrient for primary productivity in the river is likely inorganic phosphorus in the water.
- The Granite Falls WWTP was the primary source of phosphorus loading within the study area.
- Results of stream metabolism analysis suggest the river is likely a net heterotrophic system, with significant oxygen demand likely coming from organisms that do not obtain food from sunlight.
- Overall, Ecology found the study data to be of acceptable quality and useable based on Ecology's credible data policy and the study objectives
- DO daily minimums do not meet (are below) the water quality criterion of 9.5 mg/L for all sites monitored in the watershed.
- The results of modeled daily DO levels and changes show:

- Warm stream temperatures, periphyton (attached bottom algae) respiration and hyporheic sediment oxygen demand (driven by nutrient inputs to the hyporheic zone) are the primary factors decreasing DO minimums.
- Phytoplankton (floating algae) photosynthesis/respiration, biochemical oxygen demand in the water column, and nitrification are all predicted to have a negligible effect on DO levels.

Recommendations

- Load and wasteload allocations are needed for WSDOT stormwater, general stormwater permit holders, tributaries, and other nonpoint sources. These load and wasteload allocations will prevent DO impairments throughout the Pilchuck River.
- Wasteload allocations for the Granite Falls WWTP are needed to control SRP and biochemical oxygen demand from June through September. These wasteload allocations are expected to eliminate the largest negative impacts to DO that are observed in the river downstream of the Granite Falls WWTP outfall.
- Full implementation of the temperature allocations in this TMDL are necessary to reach the maximum improvement for DO concentrations.
- Quantify dissolved organic carbon or carbonaceous BOD loading from groundwater, small tributaries, and off stream wetlands and lakes.

Commented [PP(200]: But will the combination of WLAs and LAs allow the standards to be met?

Reasonable Assurance

{WQP lead writes this section.
This section is required *only* if compliance with water quality standards will require pollutant reductions by both point and nonpoint sources. The purpose is to explain why we believe the nonpoint reductions will occur so it will not be necessary to place the entire burden on point sources.}
When establishing a TMDL, reductions of a particular pollutant are allocated among the pollutant sources (both point and nonpoint sources) in the water body. For the water-body name and pollutant(s) TMDL, both point and nonpoint sources exist. TMDL projects (and related implementation plans) must show "reasonable assurance" that these sources will be reduced to their allocated amount. Education; outreach; technical and financial assistance; permit administration; and enforcement will all be used to ensure that the goals of this TMDL project are met.

Ecology believes that the following activities already support this TMDL project and add to the assurance that pollutant in the water-body name will meet conditions provided by Washington State water quality standards. This assumes that the activities described below are continued and maintained.

The goal of the water-body name Water Quality Improvement Report for pollutant is to help the waters of the basin meet the state's water quality standards. Describe local participation, such as: There is considerable interest and local involvement toward resolving the water quality problems in the water-body name. Numerous organizations and agencies are already engaged in stream restoration and source correction actions that will help resolve the parameter(s) problem. The following rationale helps provide reasonable assurance that the water-body name nonpoint source TMDL goals will be met by target date.

{EPA requires some assurances that TMDL implementation measures will actually occur. To that end, responsible parties, regulatory authorities, detailed implementation measures and schedules, and funding mechanisms must be identified. To provide this assurance, include specific details of the people, actions, timelines, and funding to accomplish the stated goals here. For each major stakeholder, evaluate and detail the following types of activities underway or planned to reduce the contribution of nonpoint pollutants:

1. Describe ongoing nonpoint source control e.g. riparian restoration projects, nonpoint stormwater best management practices (BMPs).
2. Discuss efforts aimed at increasing awareness through educational efforts, for example, conservation district outreach, pamphlets, mailers, and workshops.
3. Describe technical assistance, available funding, and other voluntary efforts, for example, local surface water management programs, grant and loan programs.
4. Describe water quality monitoring to provide feedback for adaptive management of source control activities.

5. Describe the legal authority that governments at various levels hold over the polluting activities for example, ordinances and property tax reductions for conservation set-asides.}

xx

While Ecology is authorized under Chapter 90.48 RCW to impose strict requirements or issue enforcement actions to achieve compliance with state water quality standards, it is the goal of all participants in the water-body name TMDL process to achieve clean water through cooperative efforts.

{Discuss role of adaptive management in fine tuning expectations over time.}

xx

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Implementation Plan

{WQP lead writes this section.}

Introduction

{Include the following paragraphs:}

This *implementation plan* was developed jointly by Ecology and interested and responsible parties. It describes what will be done to improve water quality. It explains the roles and authorities of cleanup partners (those organizations with jurisdiction, authority, or direct responsibility for cleanup), along with the programs or other means through which they will address these water quality issues. It prioritizes specific actions planned to improve water quality and achieve water quality standards. It expands on the recommendations made in Part 1 of this report.

Typically, Ecology produces an implementation strategy, which is submitted with the technical analysis to the U.S. Environmental Protection Agency (EPA) for TMDL approval as part of the water quality improvement report (WQIR). Then, following EPA's approval, Ecology and interested and responsible parties develop a water quality implementation plan. However, this section of this water quality improvement report will serve as both the implementation *strategy* and the implementation *plan*.

This implementation plan describes how xx pollutant levels will be reduced to meet water quality standards. xx TMDL reductions should be achieved by 20xx in the xx.

Who needs to participate in implementation?

{Provide local, tribe, state, and federal groups who will coordinate actions. Identify any regulatory authorities.

Very briefly describe the role of each entity cited.}

xx

Pollution sources and organizational actions, goals, and schedules

{Summarize needed implementation actions based on recommendations in the Study section.}

xx

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Activities to address pollution sources

{This list must show **ALL implementation activities necessary to achieve compliance with water quality standards**, not just those that have a willing implementer and timeline. List anticipated implementation activities, as well as specific and scheduled already on-going activities. This is flexible– if the community is ready, proceed with details on activities planned. Or, add more detail to this overview.

Provide a general idea of local, tribe, state, and federal groups who may coordinate actions. Identify any regulatory authorities. Very briefly describe the role of each entity cited.

Define current and agreed-to future implementation activities, organizations involved, resources needed, goals, schedule of actions.

Provide details of who will do what, where, and by when: Insert a chart of organizations involved with implementation and their goals, tasks (performance measures) and timelines to help reduce pollution.

Include a section in the table for needed implementation actions that are not yet assigned to, or being done by a particular entity.}

xx

{If applicable, include the following Forest and Fish standard language:}

The state's forest practices regulations will be relied upon to bring waters into compliance with the load allocations established in this TMDL project on private and state forest lands. This strategy, referred to as the Clean Water Act Assurances, was established as a formal agreement to the 1999 Forests and Fish Report (www.dnr.wa.gov/Publications/fp_rules_forestsandfish.pdf).

The state's forest practices rules were developed with the expectation that the stream buffers and harvest management prescriptions were stringent enough to meet state water quality standards for temperature and turbidity, and provide protection equal to what would be required under a TMDL. As part of the 1999 agreement, new forest practices rules for roads were also established. These new road construction and maintenance standards are intended to provide better control of road-related sediments, provide better stream bank stability protection, and meet current best management practices.

To ensure the rules are as effective as assumed, a formal adaptive management program was established to assess and revise the forest practices rules, as needed. The agreement to rely on the forest practices rules in lieu of developing separate TMDL load allocations or implementation requirements for forestry is conditioned on maintaining an effective adaptive management program.

Consistent with the directives of the 1999 Forests and Fish agreement, Ecology conducted a formal 10-year review of the forest practices and adaptive management programs in 2009:

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www.ecy.wa.gov/programs/wq/nonpoint/ForestPractices/CWAassurances-FinalRevPaper071509-W97.pdf

Ecology noted numerous areas where improvements were needed, but also recognized the state's forest practices program provides a substantial framework for bringing the forest practices rules and activities into full compliance with the water quality standards. Therefore, Ecology decided to conditionally extend the CWA assurances with the intent to stimulate the needed improvements. Ecology, in consultation with key stakeholders, established specific milestones for program accomplishment and improvement. These milestones were designed to provide Ecology and the public with confidence that forest practices in the state will be conducted in a manner that does not cause or contribute to a violation of the state water quality standards.

The success of this TMDL project will be assessed using monitoring data from streams in the watershed.

{If applicable, include the following example planning language: Use <H3> stiyle for the title.

State Environmental Policy Act and Land Use Planning

Consider TMDLs during State Environmental Policy Act (SEPA) and other local land use planning reviews. If the land use action under review is known to potentially impact temperature and dissolved oxygen as addressed by this TMDL project, then the project may have a significant adverse environmental impact. SEPA lead agencies and reviewers are required to look at potentially significant environmental impacts and alternatives and to document that the necessary environmental analyses have been made. Land-use planners and project managers should consider findings and actions in this TMDL project to help prevent new land uses from violating water quality standards. Ecology recently published a focus sheet on how TMDLs play a role in SEPA impact analysis, threshold determinations, and mitigation (https://fortress.wa.gov/ecy/publications/SummaryPages/0806008.html). Additionally, the TMDL should be considered in the issuance of land use permits by local authorities.}

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Measuring Progress toward Goals

{This section includes plans to measure whether implementation activities have been completed and if interim targets and water quality standards are being met. The load/wasteload allocations are stated as the goals/targets.

Include date that the water bodies are expected to meet standards.}

xx

Performance measures and targets

{This is how to track and evaluate the progress of proposed implementation activities (i.e., tracking whether or not a specified entity printed an education brochure they agreed to publish). Reference Appendix. Appendix includes tables to track the progress of implementation activities for each organization listed in the *Pollution Sources and Organizational Actions, Goals, and Schedules* section of this report.

Describe how and when Ecology will review the implementation projects completed with the advisory group or local interest groups.

Required by the MOA with EPA:

1. Timeframes for meeting interim targets and water quality standards.
2. A detailed plan to implement control actions to meet load allocations for nonpoint sources.
3. A detailed monitoring plan to measure implementation activities and achievement of interim targets and water quality standards.
4. Additional implementation measures which Ecology intends to use should initial implementation activities not be implemented or not be effective.}

xx

Effectiveness monitoring plan

Effectiveness monitoring determines if the interim targets and water quality standards have been met after the measures described in the water quality implementation plan are functioning (i.e, the instream water quality monitoring). Effectiveness monitoring of TMDL projects is usually conducted by the EA Program. This plan includes monitoring that will be done by other entities if there is any planned.

{This is an element of adaptive management. It provides real-time feedback process to determine cleanup effectiveness and support adaptive management.

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EAP technical lead makes general recommendations, and negotiates and reviews content with WQP lead for final draft. Set minimal monitoring to be done – targets to see if meeting goals.

xx

Define objectives of post-TMDL project monitoring (EAP and WQP). Post-TMDL project monitoring design (may be conceptual at this point). Describe ongoing monitoring program to evaluate success of cleanup actions.

WQP lead works with locals on plan. Describe monitoring programs by other partners. Include the following text :}

Monitor the implementation actions and how they are maintained.

Monitoring to determine the quality of water after implementation has occurred will be needed when water quality standards are believed to be achieved.

Entities with enforcement authority will be responsible for following up on any enforcement actions. Stormwater permittees will be responsible for meeting the requirements of their permits. Those conducting restoration projects or installing BMPs will be responsible for monitoring plant survival rates and maintenance of improvements, structures, and fencing.

Adaptive management

{Discuss additional implementation measures which Ecology/ the advisory group intends to use should initial implementation activities not be implemented or effective.

Include the statement that if water quality standards are achieved, but wasteload and load allocations are not, the TMDL project will be considered satisfied.}

Natural systems are complex and dynamic. The way a system will respond to human management activities is often unknown and can only be described as probabilities or possibilities. Adaptive management involves testing, monitoring, evaluating applied strategies, and incorporating new knowledge into management approaches that are based on scientific findings. In the case of TMDL projects, Ecology uses adaptive management to assess whether the actions identified as necessary to solve the identified pollution problems are the correct ones and whether they are working. As we implement these actions, the system will respond, and it will also change. Adaptive management allows us to fine-tune our actions to make them more effective, and to try new strategies if we have evidence that a new approach could help us to achieve compliance.

TMDL reductions should be achieved by 20xx. {Describe interim targets in terms of concentrations and/or loads, as well as in terms of implemented cleanup actions.} These targets will be described in terms of percent reductions, concentrations, and implementation activities.

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Partners will work together to monitor progress towards these goals, evaluate successes, obstacles, and changing needs, and make adjustments to the implementation strategy as needed.

Ecology will use adaptive management when water monitoring data show that the TMDL project targets are not being met or implementation activities are not producing the desired result. A feedback loop (Figure xx) consisting of the following steps will be implemented:

Step 1. The activities in the water quality implementation plan are put into practice.

Step 2. Programs and best management practices (BMPs) are evaluated for technical adequacy of design and installation.

Step 3. The effectiveness of the activities is evaluated by assessing new monitoring data and comparing it to the data used to set the TMDL project targets.

- Step 3a. If the goals and objectives are achieved, the implementation efforts are adequate as designed, installed, and maintained. Project success and accomplishments should be publicized and reported to continue project implementation and increase public support.
- Step 3b. If not, then BMPs and the implementation plan will be modified or new actions identified. The new or modified activities are then applied as in Step 1.

Additional monitoring may be necessary to better isolate the bacteria sources so that new BMPs can be designed and implemented to address all sources of bacteria to the streams.

It is ultimately Ecology's responsibility to assure that implementation is being actively pursued and water standards are achieved.

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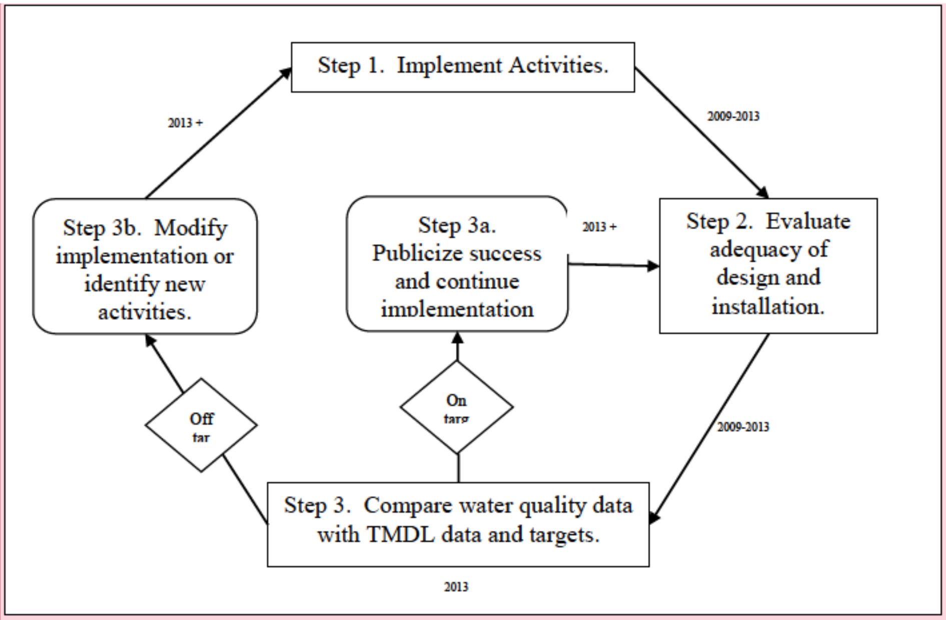

Figure 46. Feedback loop for determining need for adaptive management.

Dates are estimates and may change depending on resources and implementation status.

See the *Effectiveness Monitoring* section in this report.

xx

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Funding Opportunities

{Identify potential funding sources – national, state, and local.

Multiple sources of financial assistance for water cleanup activities are available through Ecology's grant and loan programs, local conservation districts, and other sources.

Refer to **www.ecy.wa.gov/programs/wq/tmdl/TMDLFunding.html** for a list and descriptions of funding sources. Choose ones appropriate to your project and include them here.}

xx

Summary of Public Involvement Methods

{Identify what you did to get the public involved in the TMDL project process, including outreach and education activities.}

xx

Commented [nlm209]: These sections are part of the WQP implementation half of the report and have not yet been developed PLEASE DO NOT REVIEW!

References

Bailey, K.R., 1998. French Creek Watershed Geologic Report. Prepared for The French Creek Watershed Management Committee and Snohomish County Surface Water Management. June 1998.

Bartholow, J.M. 2000. Estimating cumulative effects of clearcutting on stream temperatures, Rivers, 7(4), 284-297.

Battin, T.J., Kaplan, L.A., Newbold, J.D. and Hendricks, S.P., 2003. A mixing model analysis of stream solute dynamics and the contribution of a hyporheic zone to ecosystem function. Freshwater Biology, 48(6), pp. 995-1014.

Borchardt, M., 1996. Nutrients. In Stevenson, R., M. Bothwell, and R. Lowe, 1996. Algal Ecology: Freshwater Benthic Ecosystems. Academic Press, San Diego, CA.

Brugger, A., Wett, B., Kolar, I., Reitner, B. and Herndl, G.J., 2001. Immobilization and bacterial utilization of dissolved organic carbon entering the riparian zone of the alpine Enns River, Austria. Aquatic Microbial Ecology, 24(2), pp. 129-142.

Chapra, S.C., 1997. Surface Water-Quality Modeling. McGraw-Hill, New York, N.Y.

Clinton, S.M., Edwards, R.T. and Naiman, R.J., 2002. . Forest-River Interactions: Influence on Hyporheic Dissolved Organic Carbon Concentrations in a Floodplain Terrace. Journal of the American Water Resources Association (JAWRA), 38(3), pp. 619-631.

Crenshaw, C.L., Valett, H.M. and Webster, J.R., 2002. Effects of augmentation of coarse particulate organic matter on metabolism and nutrient retention in hyporheic sediments. Freshwater Biology, 47(10), pp. 1820-1831.

Danielopol, D.L., 1989. Groundwater fauna associated with riverine aquifers. Journal of the North American Benthological Society, pp. 18-35.

De Baar, H.J.W., 1994. von Liebig's law of the minimum and plankton ecology (1899–1991). Progress in Oceanography, 33(4), pp. 347-386.

Ecology, 1997. Water Quality Assessment of Tributaries to the Snohomish River and Nonpoint Source Pollution TMDL Study. Washington State Department of Ecology, Olympia, WA. September 1997. Publication No. 97-334.
https://fortress.wa.gov/ecy/publications/SummaryPages/97334 html

Ecology, 2015a. Fact Sheet for NPDES Permit WA0021130: Granite Falls Wastewater Treatment Plant. Washington State Department of Ecology. 4/15/15.

Ecology, 2015b. Fact Sheet for the Sand and Gravel General Permit. Washington State Department of Ecology. Olympia, WA. http://www.ecy.wa.gov/programs/wq/sand/documents/2015FactSheet.pdf

Ecology, 2015c. TTools for ArcGIS. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/models html

Fellows, C.S., Valett, M.H. and Dahm, C.N., 2001. Whole‐stream metabolism in two montane streams: Contribution of the hyporheic zone. Limnology and Oceanography, 46(3), pp. 523-531.

Franklin, J.R. and C.T. Dryness, 1973. Natural vegetation of Oregon and Washington. Pacific Northwest Forest and Range Experimentation, Forest Service, U.S. Department of Agriculture, Portland, OR.

Frazer, G.W., Canham, C.D., and Lertzman, K.P., 1999. Gap Light Analyzer (GLA): Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, user's manual and program documentation. Copyright © 1999: Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York.

French Creek Watershed Management Committee, 2004. French Creek Watershed Management Plan. French Creek Watershed Management Council, Everett, WA.

Grimm, N.B. and Fisher, S.G., 1984. Exchange between interstitial and surface water: implications for stream metabolism and nutrient cycling. Hydrobiologia, 111(3), pp. 219-228.

Hannah, D.M., Malcolm, I.A. and Bradley, C., 2009. Seasonal hyporheic temperature dynamics over riffle bedforms. Hydrological Processes, 23(15), pp. 2178-2194.

Hobson, A.J., Neilson, B.T., von Stackelberg, N., Shupryt, M., Ostermiller, J., Pelletier, G. and Chapra, S.C., 2014. Development of a Minimalistic Data Collection Strategy for QUAL2Kw. Journal of Water Resources Planning and Management, 141(8), p. 04014096.

Horner, R.R., Welch, E.B. and Veenstra, R.B., 1983. Development of nuisance periphytic algae in laboratory streams in relation to enrichment and velocity. In Periphyton of freshwater ecosystems (pp. 121-134). Springer Netherlands.

Jacoby, J., & Welch, E. (2004). Pollutant effects in freshwater: applied limnology. CRC Press.

Larned, S.T., 2010. A prospectus for periphyton: recent and future ecological research. Journal of the North American Benthological Society, 29(1), pp. 182-206.

Mathieu, N., 2011. Salmon Creek Watershed Low Dissolved Oxygen and pH Characterization Study. Washington State Department of Ecology Water Quality Program, P.O. Box 47600, Olympia, WA, 98504-7600 Publication No. 13-03-013. https://fortress.wa.gov/ecy/publications/SummaryPages/1303013 html

Mathieu, N., 2014. Addendum to Quality Assurance Project Plan: French Creek and Pilchuck River Temperature, Dissolved Oxygen, and pH Total Maximum Daily Load. Washington State Department of Ecology Water Quality Program, P.O. Box 47600, Olympia, WA, 98504-7600 Publication No. 14-03-112.
https://fortress.wa.gov/ecy/publications/SummaryPages/1403112 html

Mathieu, N., 2016. Addendum 2 to Quality Assurance Project Plan: French Creek and Pilchuck River Temperature, Dissolved Oxygen, and pH Total Maximum Daily Load. Washington State Department of Ecology Water Quality Program, P.O. Box 47600, Olympia, WA, 98504-7600 Publication No. 16-03-115.
https://fortress.wa.gov/ecy/publications/SummaryPages/1603115 html

Mei, Y., Hornberger, G.M., Kaplan, L.A., Newbold, J.D. and Aufdenkampe, A.K., 2012. Estimation of dissolved organic carbon contribution from hillslope soils to a headwater stream. Water Resources Research, 48(9).

MEL, 2008. Manchester Environmental Laboratory Lab Users Manual, Ninth Edition. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

Mulholland, P.J., Marzolf, E.R., Webster, J.R., Hart, D.R. and Hendricks, S.P., 1997. Evidence that hyporheic zones increase heterotrophic metabolism and phosphorus uptake in forest streams. Limnology and Oceanography, 42(3), pp. 443-451.

Mulholland, P.J., Fellows, C.S., Tank, J.L., Grimm, N.B., Webster, J.R., Hamilton, S.K., Martí, E., Ashkenas, L., Bowden, W.B., Dodds, W.K. and McDowell, W.H., 2001. Inter-biome comparison of factors controlling stream metabolism. Freshwater Biology, 46(11), pp. 1503-1517.

Pelletier, G., 2013. RMA.xls - River metabolism analyzer for continuous monitoring data. Washington State Department of Ecology, Olympia, WA.
www.ecy.wa.gov/programs/eap/models html

Pelletier, G., 2015. Shade xls: a tool for estimating shade from riparian vegetation. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/models html

Pelletier, G. and S. Chapra, 2008. QUAL2Kw: a modeling framework for simulating river and stream water quality. User's Manual, Theory and documentation.
http://www.ecy.wa.gov/programs/eap/models html

Quinn, J. M., 1991. Guidelines for the control of undesirable biological growths in water. Consultancy Report No. 6213/2. National Institute of Water and Atmospheric Research, Hamilton, New Zealand.

Redfield, A. C., 1934. On the proportions of organic derivatives in sea water and their relation to the composition of plankton (pp. 176-92). Liverpool, UK: University Press of Liverpool.

Redfield, A. C., 1958. The biological control of chemical factors in the environment. American scientist, 230A-221.

Sanderson, T.L. and P.J. Pickett, 2014. A Synopsis of Model Quality from the Department of Ecology's Total Maximum Daily Load Technical Studies. Washington State Department of Ecology, Olympia, WA. Publication No. 14-03-042.

Savery, A., and A. Hook, 2003. Habitat Conditions and Chinook Use in the Pilchuck River. Tulalip Tribes Natural Resources Department, Marysville, Washington, USA.

Schanz, F., and Juon, H., 1983. Two different methods of evaluating nutrient limitations of periphyton bioassays, using water from the River Rhine and eight of its tributaries. Hydrobiologia, 102(3), 187-195.

Snohomish County Assessor, 2012. https://snohomishcountywa.gov/2934/Assessor.

Snohomish Basin Salmon Recovery Forum (SBSRF), 2005. Snohomish River Basin Salmon Conservation Plan. Snohomish County Department of Public Works, Surface Water Management Division. Everett, WA.
https://snohomishcountywa.gov/ArchiveCenter/ViewFile/Item/2153

Snohomish County Surface Water Management (SCSWM), 2012. Middle Pilchuck River assessment - habitat report. Prepared by Snohomish County, for the Salmon Recovery Funding Board. 61 pp.

Svrjcek, R., 2003. Lower Snohomish River Tributaries Fecal Coliform Total Maximum Daily Load Detailed Implementation Plan. Washington State Department of Ecology Water Quality Program, P.O. Box 47600, Olympia, WA, 98504-7600. Publication No. 03-10-031.
https://fortress.wa.gov/ecy/publications/SummaryPages/0310031 html

Swanson, T., A. King, N. Gurdian, and J. Zhen, 2012. French Creek and Pilchuck River Temperature, Dissolved Oxygen, and pH Total Maximum Daily Load Water Quality Study Design (Quality Assurance Project Plan). Washington State Department of Ecology, Olympia, WA. Publication No. 12-03-114.
https://fortress.wa.gov/ecy/publications/SummaryPages/1203114 html

Thornburgh, K. and G. Williams, 2000. The State of the Waters, Water Quality in Snohomish County's Rivers, Stream, and Lakes. Snohomish County Department of Public Works, Surface Water Management, Everett, WA.

Thornburgh, K, K., Nelson, K. Rawson, and G. Lucchetti, 1991. Snohomish System Water Quality Study 1987-90. Tulalip Fisheries Department Progress Report. Tulalip Fisheries Department, Marysville, WA 98270.

Tooley, et al., 1990. Data Appendix: Timber-Fish-Wildlife - Evaluation of Prediction Models and Characterization of Stream Temperature Regimes in Washington.
www.ecy.wa.gov/biblio/90e75 html

USGS, 2017. USGS Real-Time Water Data for Washington: Streamflow. Snoqualmie/Snohomish River Basin station: 12155300. National Water Information System: Web Interface. United States Geological Survey. https://waterdata.usgs.gov/WA/nwis/current/?type=flow

WAC 173-201A. Water Quality Standards for Surface Waters in the State of Washington. Washington State Department of Ecology, Olympia, WA.
www.ecy.wa.gov/biblio/wac173201a.html

Welch, E.B., Jacoby, J.M., Horner, R.R. and Seeley, M.R., 1988. Nuisance biomass levels of periphytic algae in streams. Hydrobiologia, 157(2), pp. 161-168.

White, D.S., 1993. Perspectives on defining and delineating hyporheic zones. Journal of the North American Benthological Society, pp. 61-69.

Wright, Robert, J, Randy Coots, and Robert F. Cusimano, 2001. Lower Snohomish River Tributaries Fecal Coliform Total Maximum Daily Submittal Report. Washington State Department of Ecology Water Quality Program, P.O. Box 47600, Olympia, WA, 98504-7600 Publication No. 00-10-087.
https://fortress.wa.gov/ecy/publications/SummaryPages/0010087 html

Appendices

Appendix A. Glossary, Acronyms, and Abbreviations

{Author, delete all terms that do not apply to this report.}

Glossary

303(d) List: Section 303(d) of the federal Clean Water Act requires Washington State periodically to prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited water bodies (ocean waters, estuaries, lakes, and streams) that fall short of state surface water quality standards and are not expected to improve within the next two years.

Best management practices (BMPs): Physical, structural, or operational practices that, when used singularly or in combination, prevent or reduce pollutant discharges.

Char: Char (genus *Salvelinus*) are distinguished from trout and salmon by the absence of teeth in the roof of the mouth, presence of light colored spots on a dark background, absence of spots on the dorsal fin, small scales, and differences in the structure of their skeleton. (Trout and salmon have dark spots on a lighter background.)

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each water body or segment, regardless of whether or not the uses are currently attained.

Extraordinary primary contact: Waters providing extraordinary protection against waterborne disease or that serve as tributaries to extraordinary quality shellfish harvesting areas.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform bacteria are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100mL).

Load allocation: The portion of a receiving water's loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading capacity: The greatest amount of a substance that a water body can receive and still meet water quality standards.

Margin of safety: Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving water body.

Municipal separate storm sewer systems (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains): (1) owned or operated by a state, city, town, borough, county, parish, district, association, or other public body having jurisdiction over disposal of wastes, stormwater, or other wastes and (2) designed or used for collecting or conveying stormwater; (3) which is not a combined sewer; and (4) which is not part of a Publicly Owned Treatment Works (POTW) as defined in the Code of Federal Regulations at 40 CFR 122.2.

National Pollutant Discharge Elimination System (NPDES): National program for issuing and revising permits, as well as imposing and enforcing pretreatment requirements, under the Clean Water Act. The NPDES permit program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to, atmospheric deposition; surface water runoff from agricultural lands; urban areas; or forest lands; subsurface or underground sources; or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System Program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Phase I stormwater permit: The first phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to medium and large municipal separate storm sewer systems (MS4s) and construction sites of five or more acres.

Phase II stormwater permit: The second phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to smaller municipal separate storm sewer systems (MS4s) and construction sites over one acre.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than five acres of land.

Pollution: Such contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Reach: A specific portion or segment of a stream.

Salmonid: Any fish that belong to the family *Salmonidae*. Basically, any species of salmon, trout, or char. www.fws.gov/le/ImpExp/FactSheetSalmonids htm

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Total maximum daily load (TMDL): A distribution of a substance in a water body designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Total suspended solids (TSS): The suspended particulate matter in a water sample as retained by a filter.

Turbidity: A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

Wasteload allocation: The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality-based effluent limitation.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Bankfull stage: Formally defined as the stream level that "corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels" (Dunne and Leopold, 1978).

Chronic critical effluent concentration: The maximum concentration of effluent during critical conditions at the boundary of the mixing zone assigned in accordance with WAC 173-201A-100. The boundary may be based on distance or a percentage of flow. Where no mixing zone is allowed, the chronic critical effluent concentration shall be 100 percent effluent.

Critical condition: When the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or designated water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 (see definition) flow event unless determined otherwise by the department.

Diel: Of, or pertaining to, a 24-hour period.

Dilution factor: The relative proportion of effluent to stream (receiving water) flows occurring at the edge of a mixing zone during critical discharge conditions as authorized in accordance with the state's mixing zone regulations at WAC 173-201A-100.

http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-020

Diurnal: Of, or pertaining to, a day or each day; daily. (1) Occurring during the daytime only, as different from nocturnal or crepuscular, or (2) Daily; related to actions which are completed in the course of a calendar day, and which typically recur every calendar day (for example, diurnal temperature rises during the day and falls during the night.)

Effective shade: The fraction of incoming solar shortwave radiation that is blocked from reaching the surface of a stream or other defined area.

Hyporheic: The area beneath and adjacent to a stream where surface water and groundwater intermix.

Near-stream disturbance zone (NSDZ): The active channel area without riparian vegetation that includes features such as gravel bars.

Riparian: Relating to the banks along a natural course of water.

System potential: The design condition used for TMDL analysis.

S**ystem-potential mature riparian vegetation:** Vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

System-potential riparian microclimate: The best estimate of air temperature reductions that are expected under mature riparian vegetation. System potential riparian microclimate can also include expected changes to wind speed and relative humidity.

System-potential temperature: An approximation of the temperatures that would occur under natural conditions. System potential is our best understanding of natural conditions that can be supported by available analytical methods. The simulation of the system-potential condition uses best estimates of *mature riparian vegetation, system potential channel morphology, and system-potential riparian microclimate* that would occur absent any human alteration.

1-DMax or 1-day maximum temperature: The highest water temperature reached on any given day. This measure can be obtained using calibrated maximum and minimum thermometers or continuous monitoring probes having sampling intervals of 30 minutes or less.

7-DADMax or 7-day average of the daily maximum temperatures: The arithmetic average of seven consecutive measures of daily maximum temperatures. The 7-DADMax for any individual day is calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the three days prior and the three days after that date.

7Q2 flow: A typical low-flow condition. The 7Q2 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every other year on average. The 7Q2 flow is commonly used to represent the average low-flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q2 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every 10 years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10 percent of the data exists and below which 90 percent of the data exists.

Acronyms and abbreviations

Commented [NE(210]: Update with important acronyms for this report

AFDW	ash-free dry weight
BMP	best management practice
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
NPDES	National Pollutant Discharge Elimination System
NSDZ	near-stream disturbance zone
RM	river mile
SOD	sediment oxygen demand
TMDL	total maximum daily load (water cleanup plan)
USGS	United States Geological Survey
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resources Inventory Area
WWTP	wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cms	cubic meters per second, a unit of flow.
dw	dry weight
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams.
km	kilometer, a unit of length equal to 1,000 meters.
m	meter
mgd	million gallons per day
mg/Kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mL	milliliters
s.u.	standard units
ug/L	micrograms per liter (parts per billion)
umhos/cm	micromhos per centimeter
uS/cm	microsiemens per centimeter, a unit of conductivity

Appendix B. Record of Public Participation

{This is required by EPA. WQP staff writes this section.}

Introduction

xx

Summary of comments and responses

xx

List of public meetings

xx

Outreach and announcements

{Include the following, if applicable:}

A 30-day public comment period for this report will be held from xx through xx, (year).

A news release was sent to all local media in the xx watershed area.

Advertisements were placed in the following publications:

- xx
- xx
- xx

Appendix C. Data Summary

xx

Appendix D. Data Quality Results

xx

Appendix E. Model Documentation

xx

Appendix F. Wasteload Allocation Details

xx

Appendix G. Detailed Water Quality Standards Information

xx

Appendix H. Detailed NPDES Facility Analysis

xx

Appendix I. Response to Public Comments

{Keep this appendix as the last appendix. Replace the "X" in the title with the appropriate letter.

Keep the following sentence in the draft report on the web site:}

This appendix will be completed after the Public Comment period.